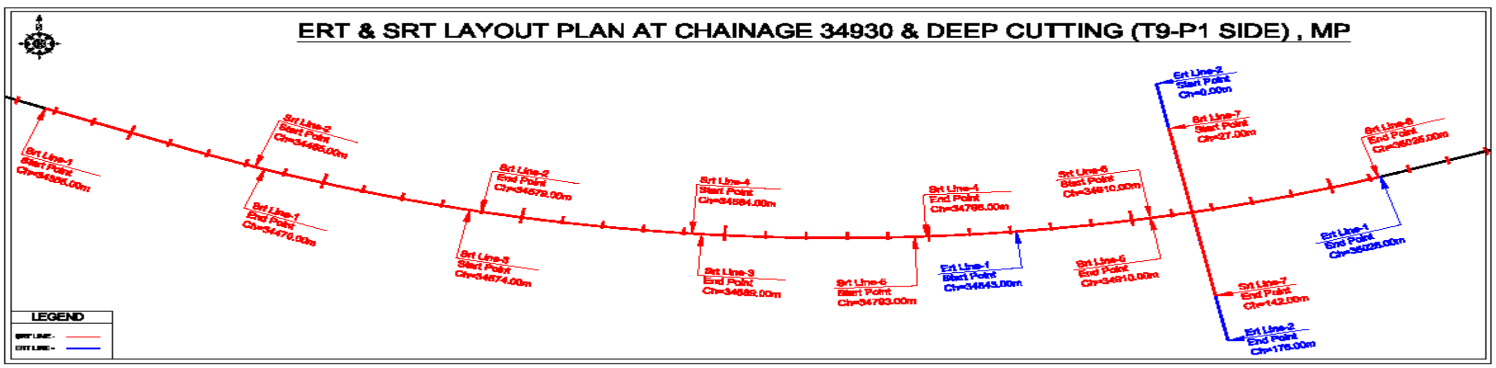
2 Geophysical of Tunnels:

2.1 Seismic section along Tunnels :

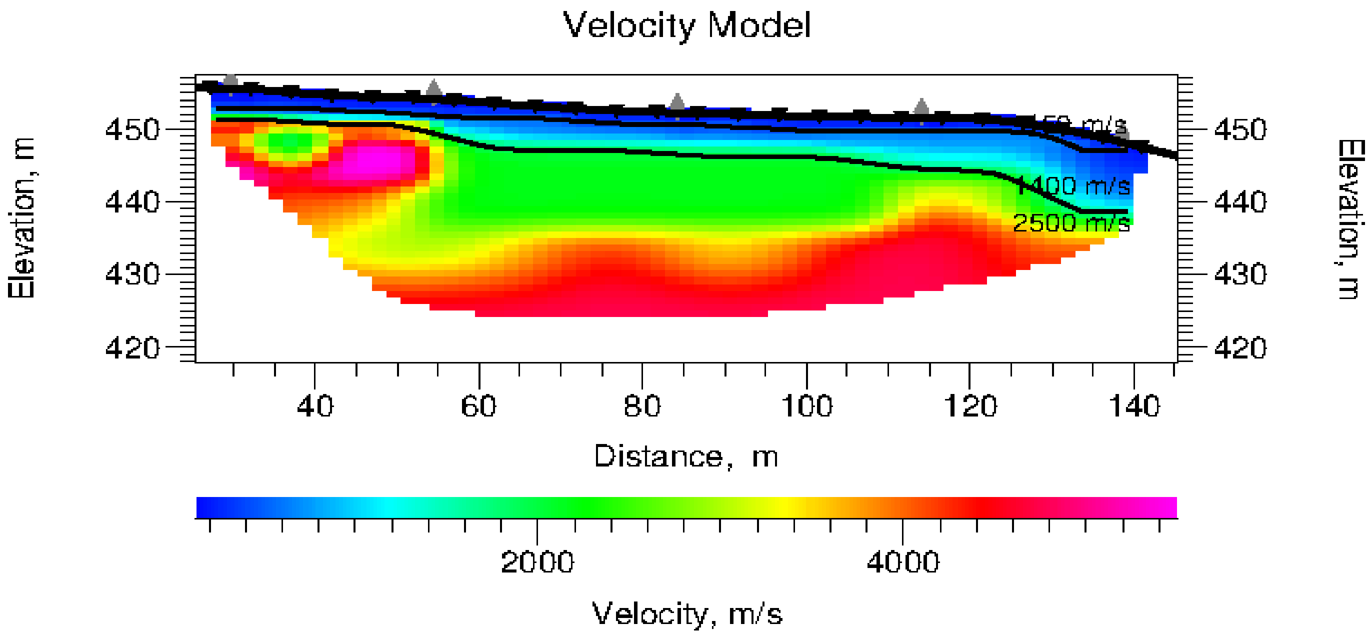
ERT & SRT LAYOUT PLAN AT CHAINAGE 34930 & Deep Cutting



Signature Not Verified

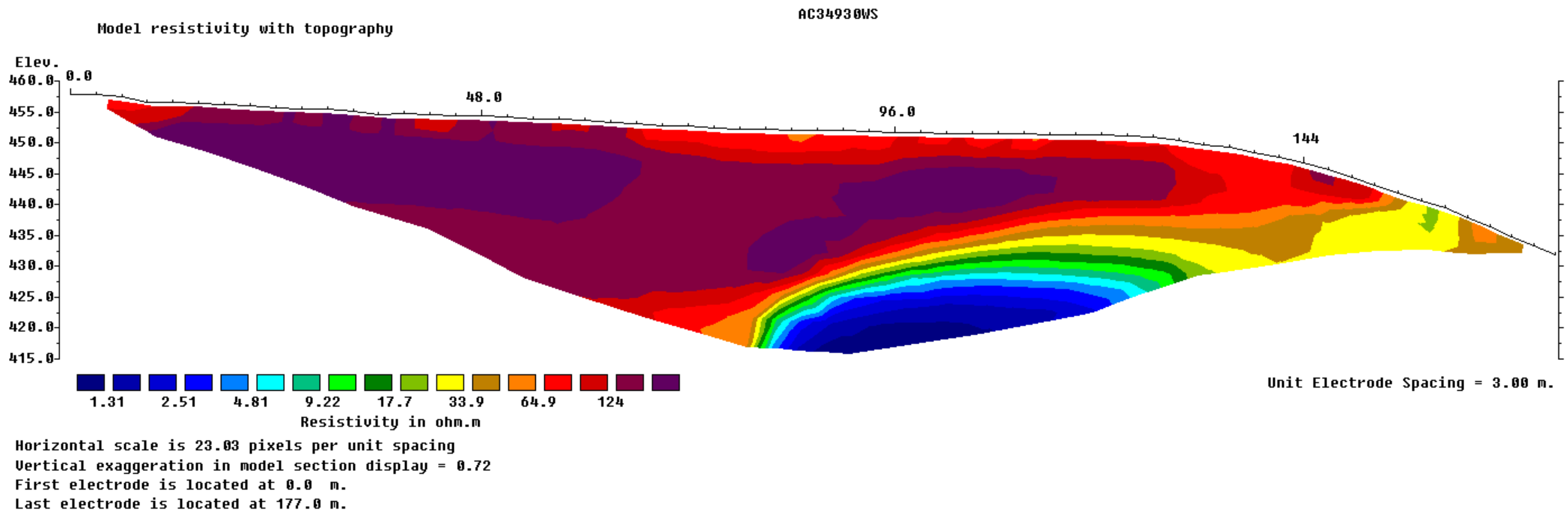
Digitally signed by Nirvesh Gour
Date: 2026.06.29 20:04:33 IST
Reason: IREPS-CRIS
Location: New Delhi

CH – 34930 Across SRT



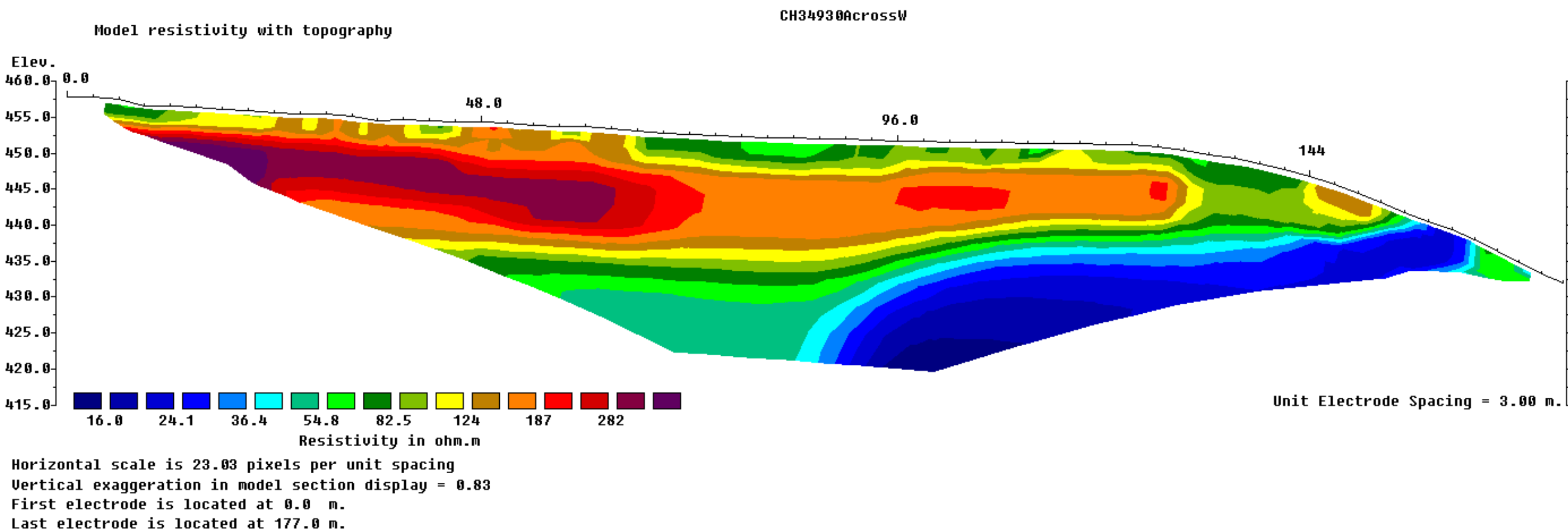
SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 1400m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 2500m/s and is likely to correspond to highly weathered rock.

CH – 34930 Across ERT – WS



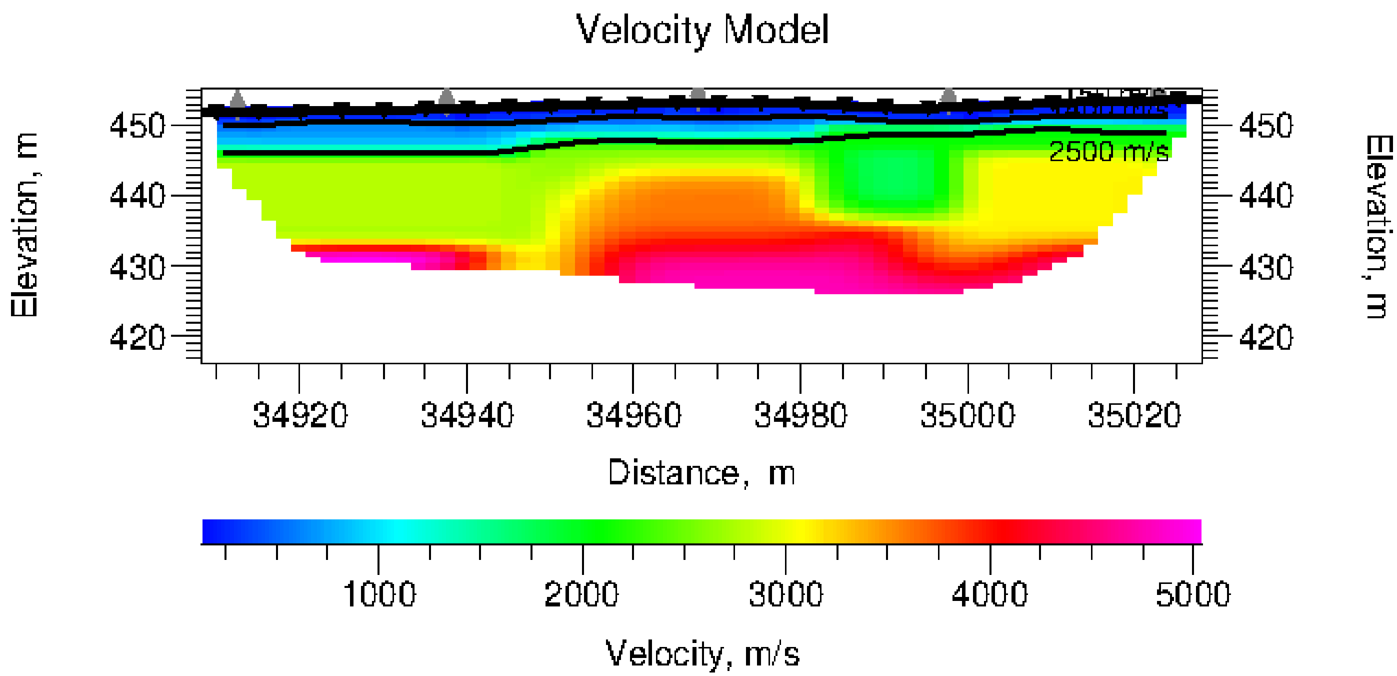
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral and vertical changes in resistivity values and lower values in the center-right bottom of the profile.

CH – 34930 Across ERT – W



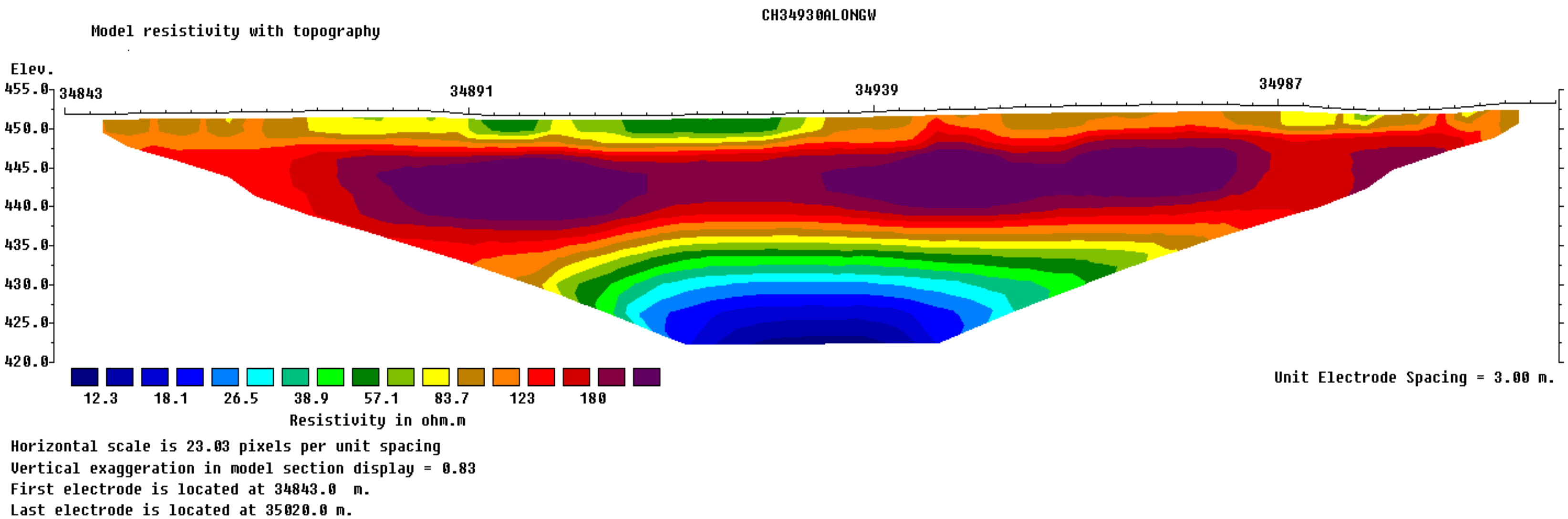
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral and vertical changes in resistivity values and lower values in the center-right bottom of the profile.

CH – 34930 Along SRT



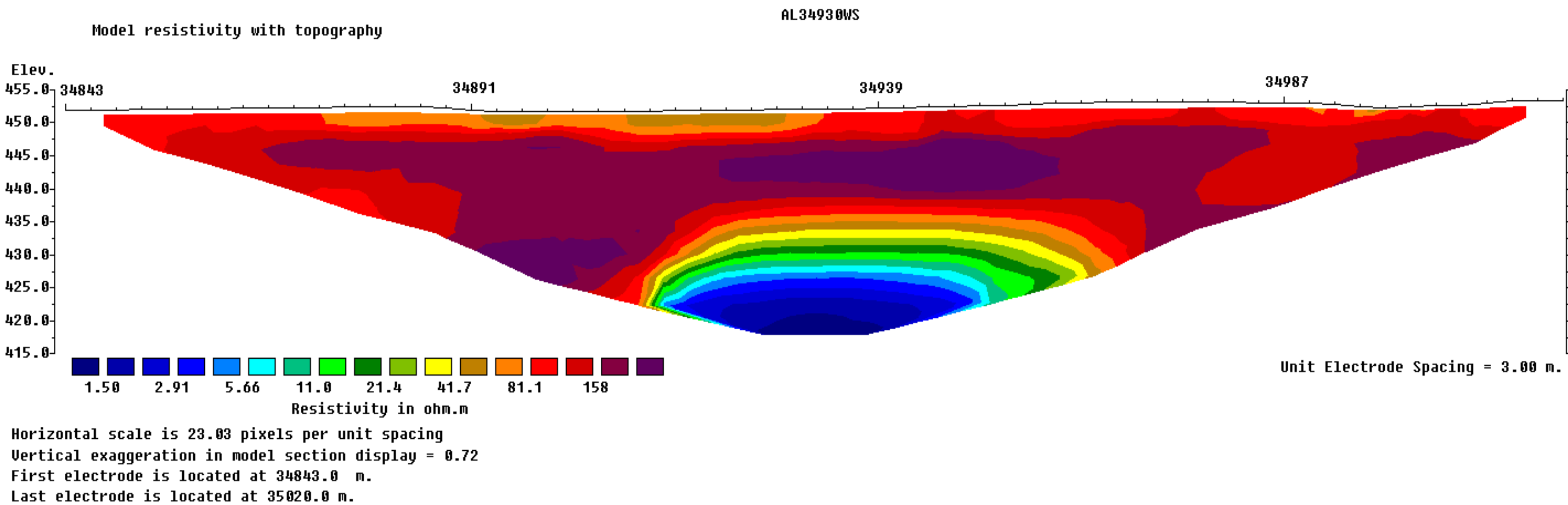
SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 1400m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 2500m/s and is likely to correspond to highly weathered rock.

CH – 34930 Along ERT – W



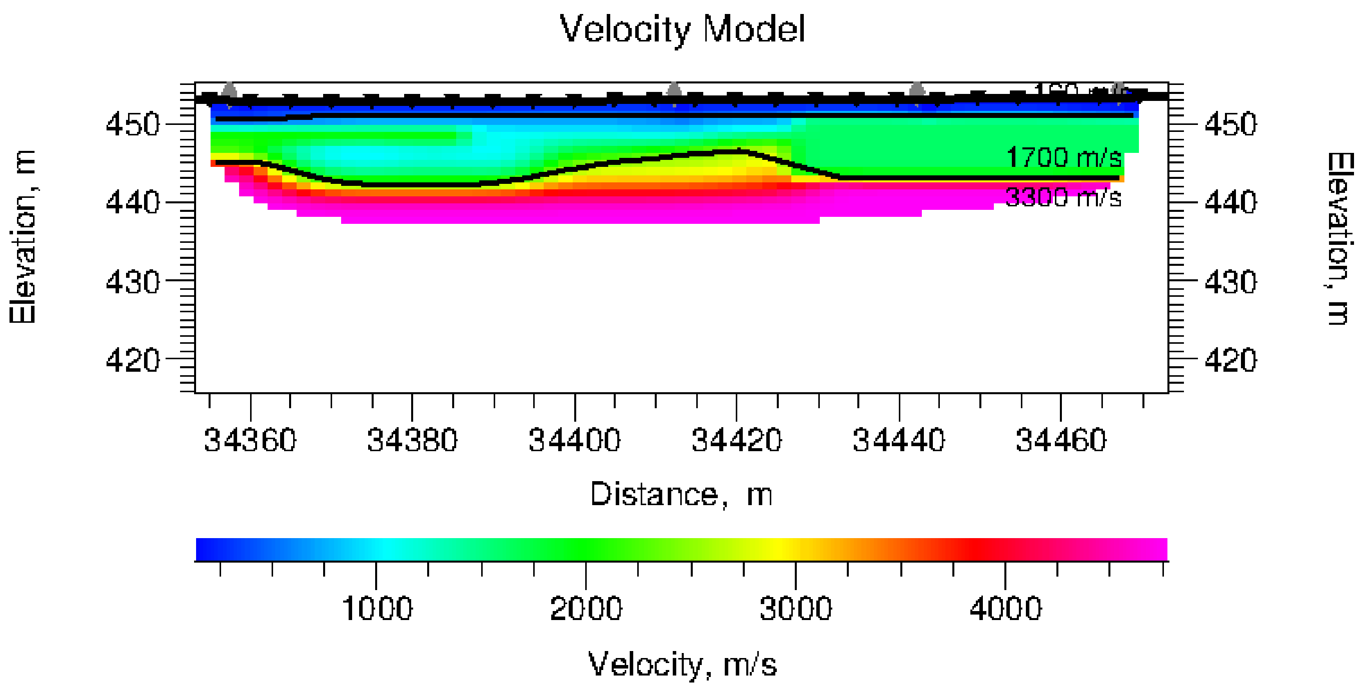
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows vertical changes in resistivity values and lower values in the bottom of the profile after a high resistivity top layer.

CH – 34930 Along ERT – WS



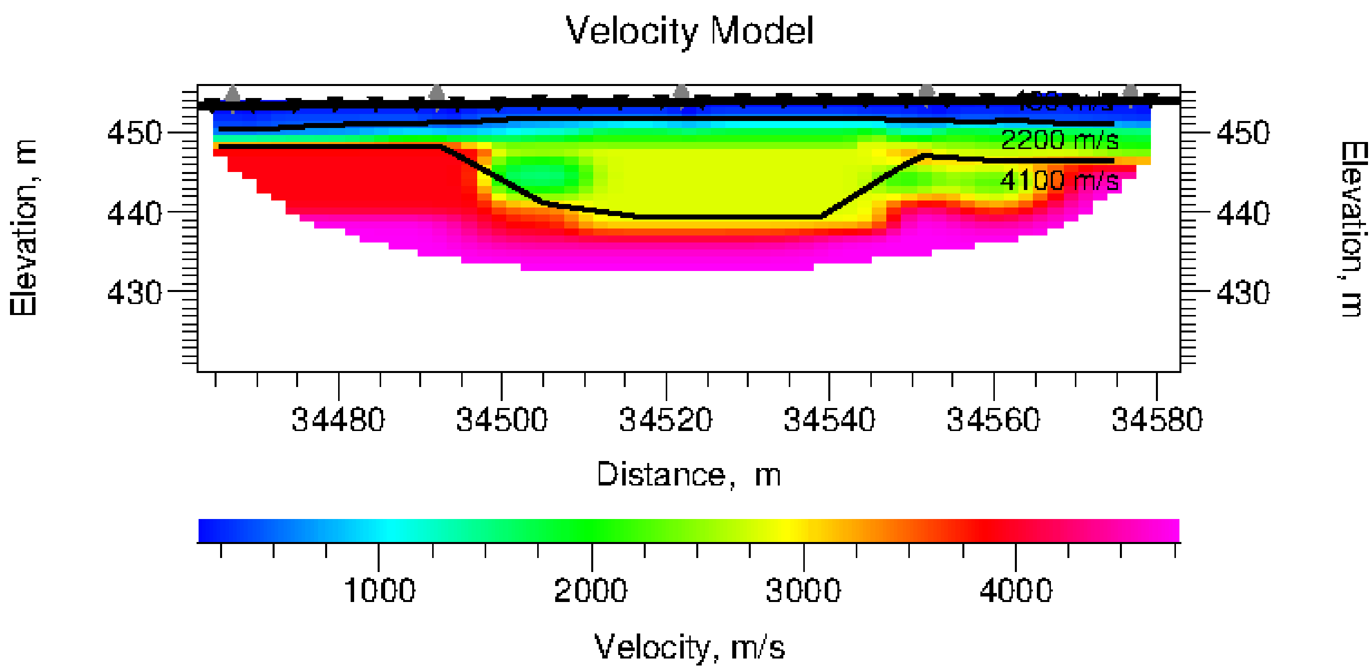
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows vertical changes in resistivity values and lower values in the bottom of the profile after a high resistivity top layer.

Deep Cuting P-1 SRT



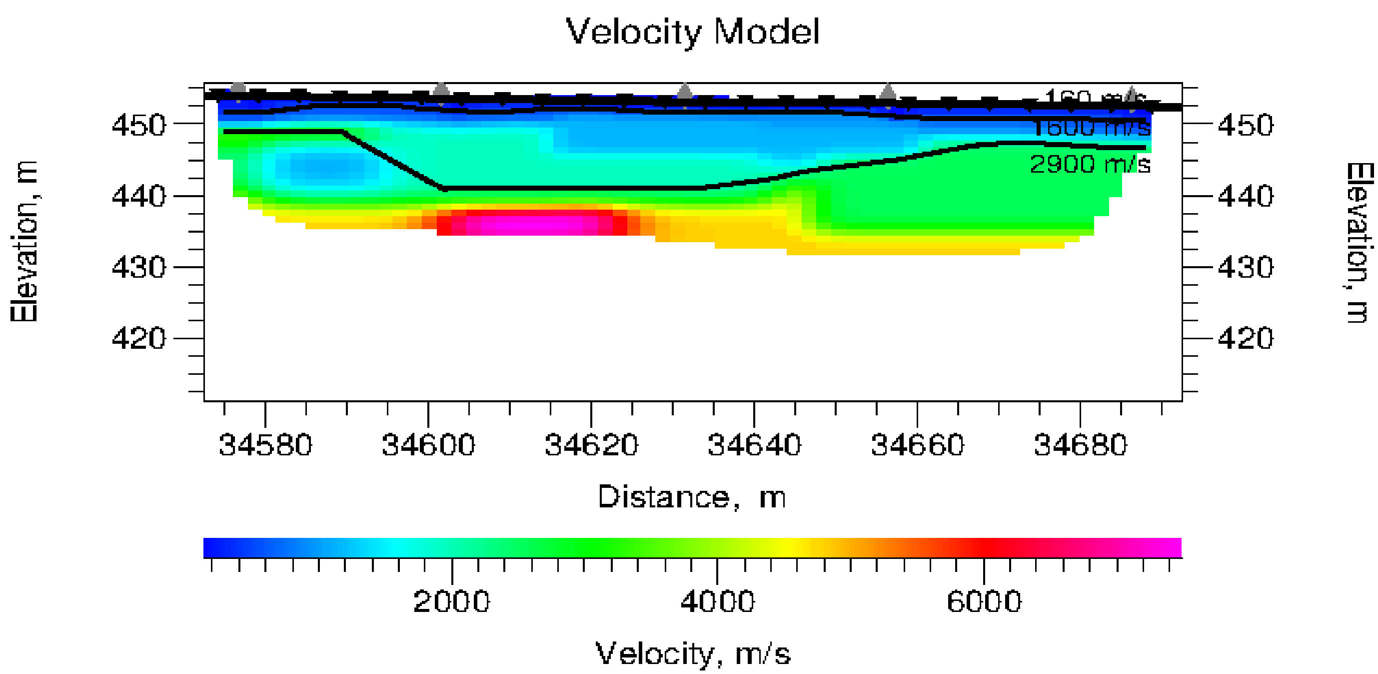
SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 1700m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 3300m/s and is likely to correspond to weathered rock.

Deep Cuting P-2 SRT



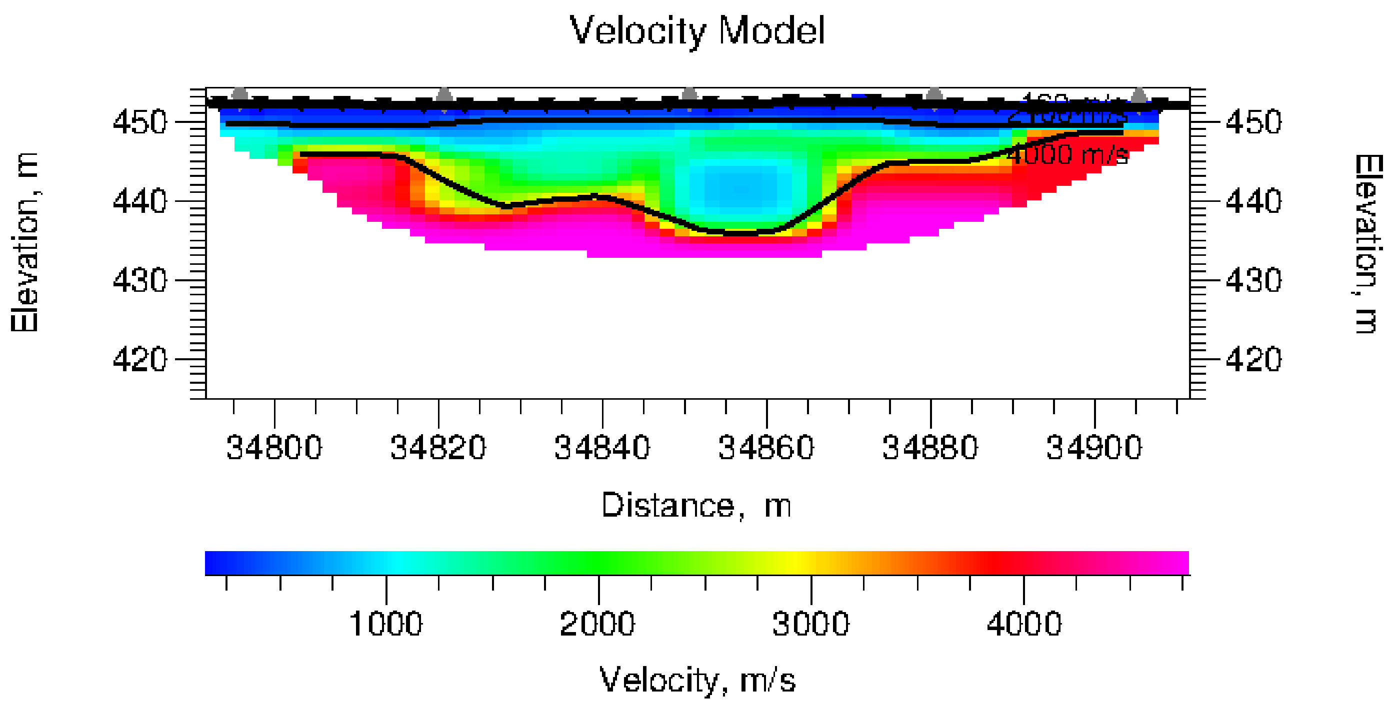
SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 2200m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 4100m/s and is likely to correspond to weathered rock. The rock is lowering in the central part.

Deep Cuting P-3 SRT



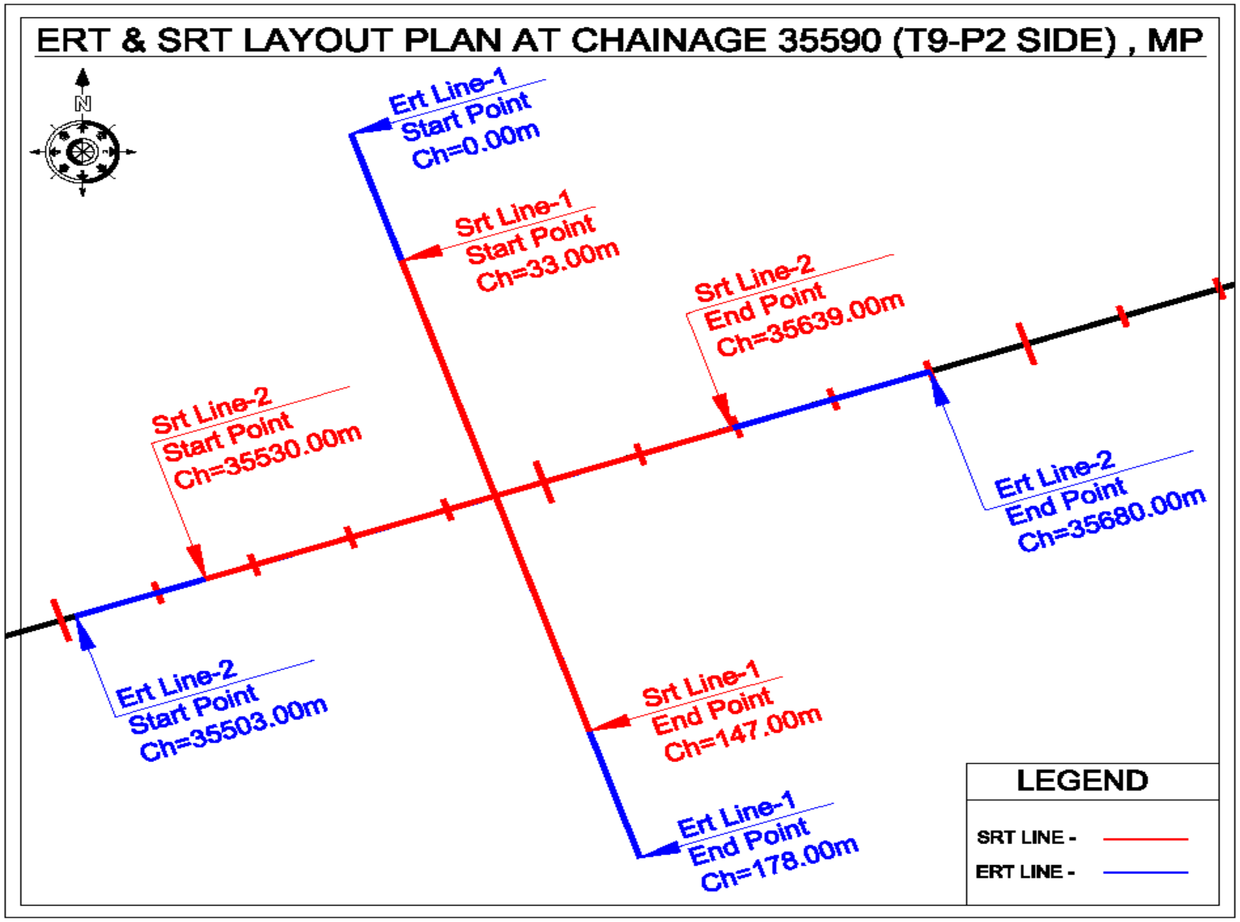
SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 1600m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 2900m/s and is likely to correspond to weathered rock.

Deep Cuting P-5 SRT

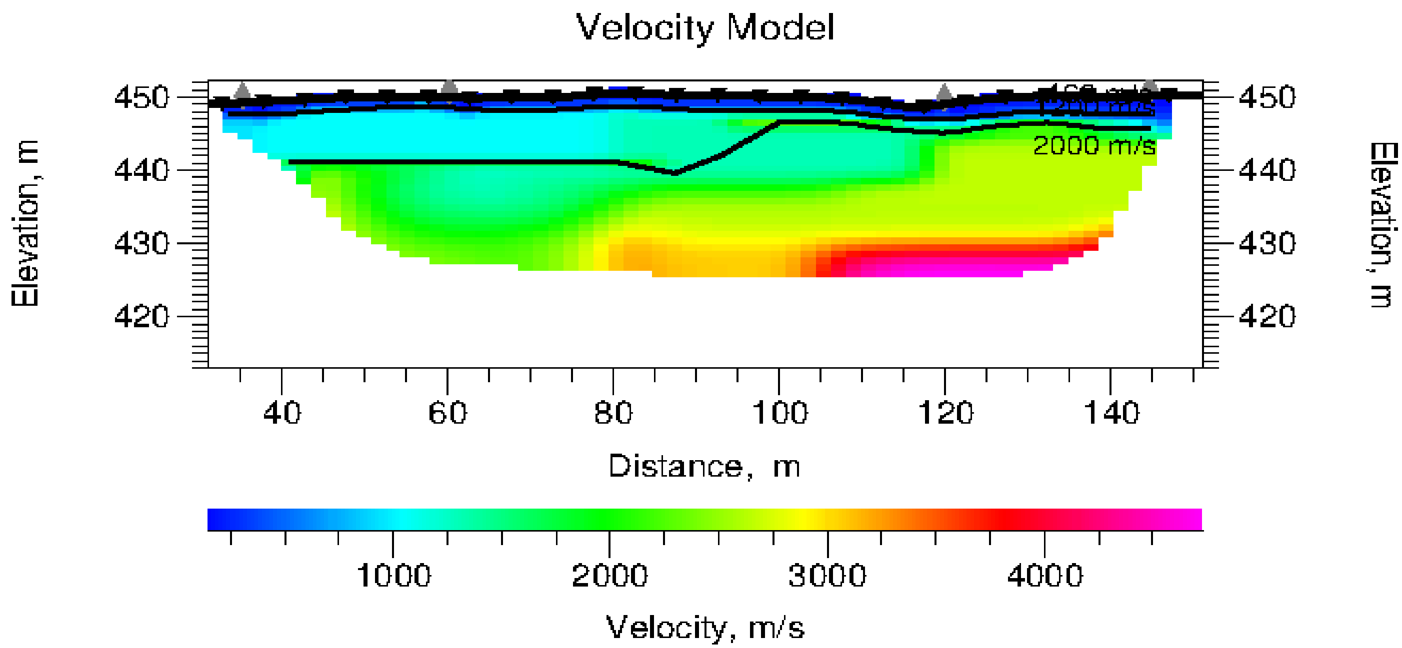


SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 2200m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 4000m/s and is likely to correspond to weathered rock. The rock is lowering in the central part.

ERT & SRT LAYOUT PLAN AT CHAINAGE 35590

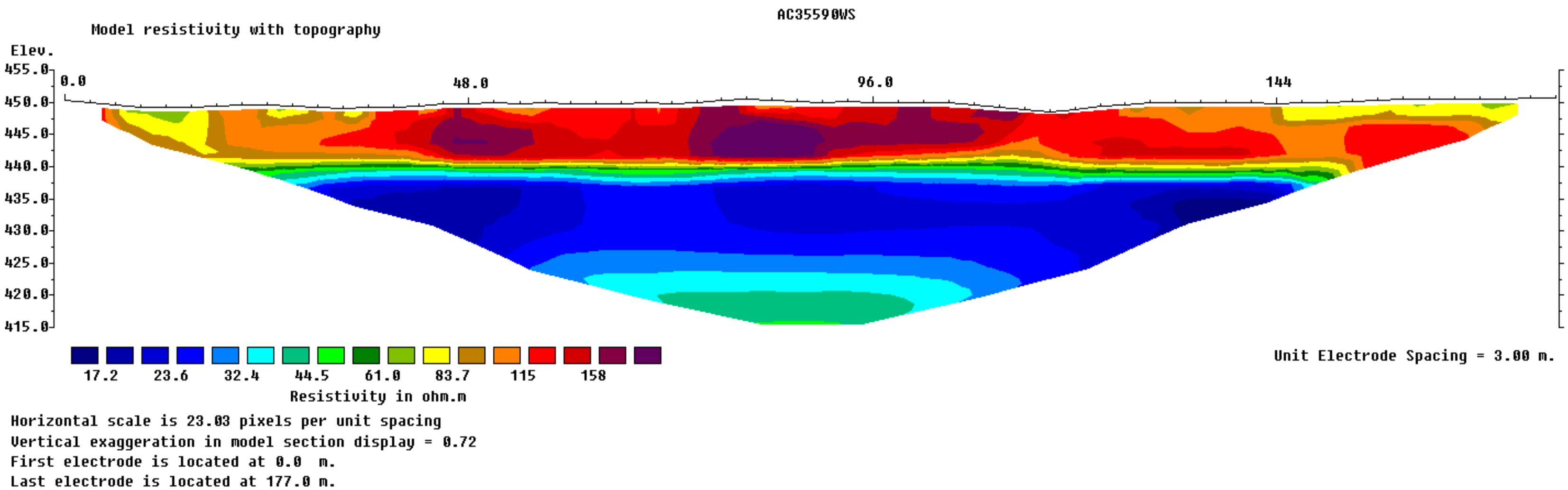


CH – 35590 Across SRT



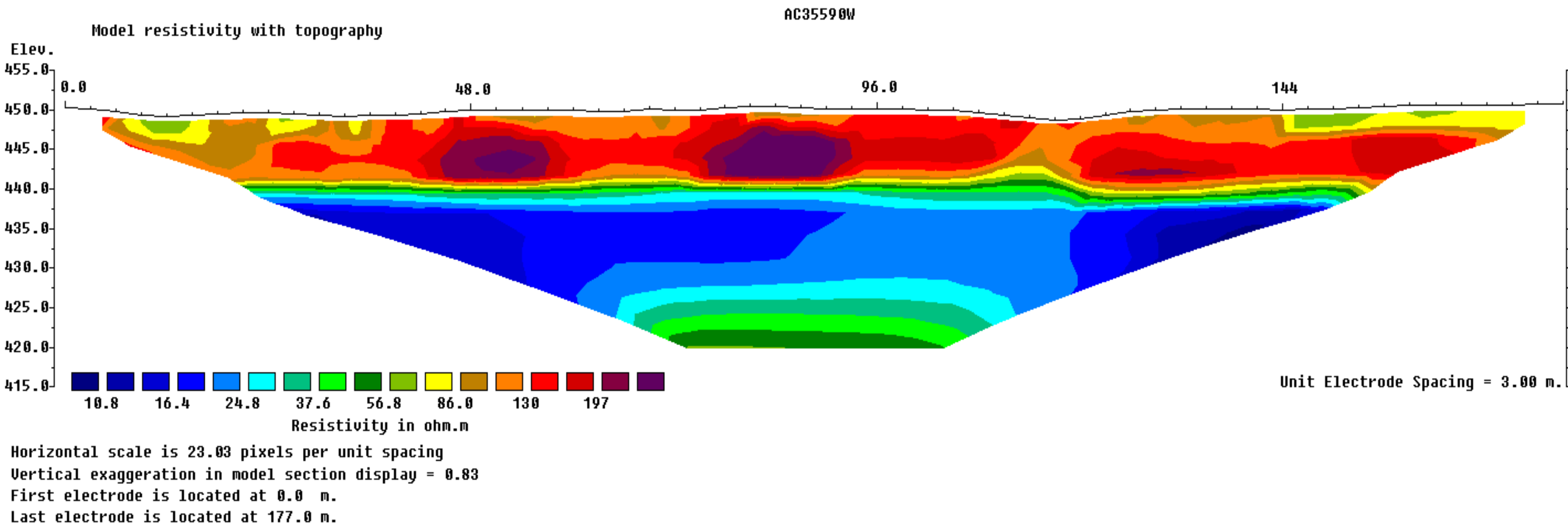
SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 1200m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 2000m/s and is likely to correspond to highly weathered rock.

CH – 35590 Across ERT – WS



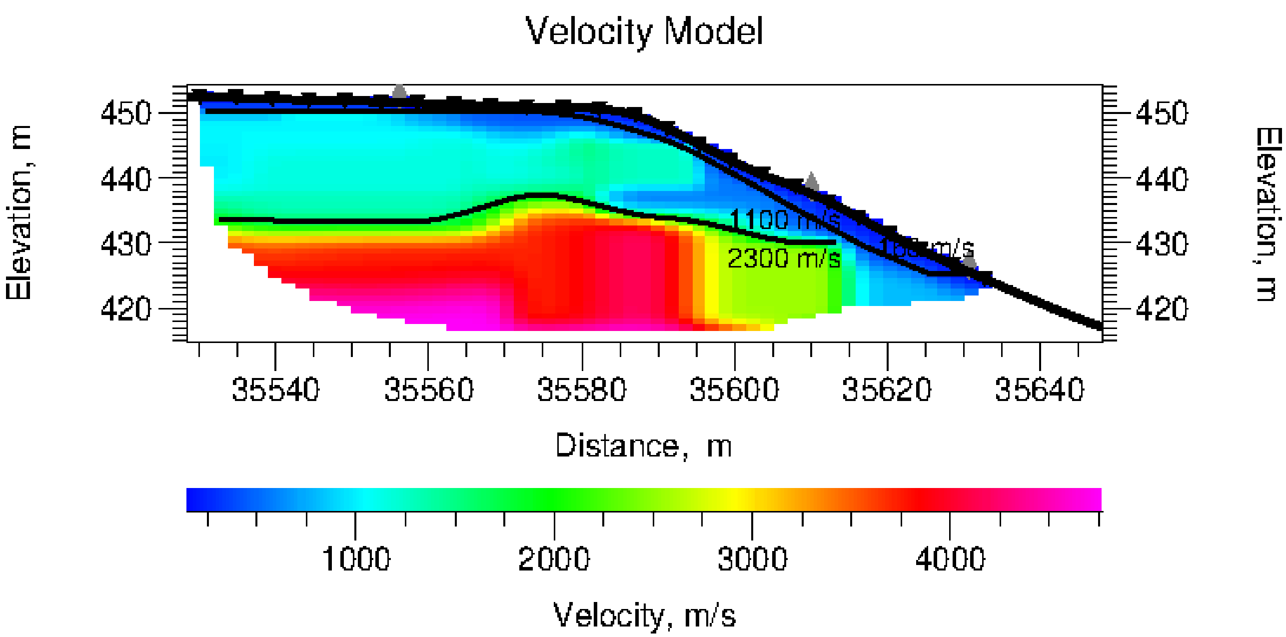
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows vertical changes in resistivity values and lower values in the middle layer of the profile.

CH – 35590 Across ERT – W



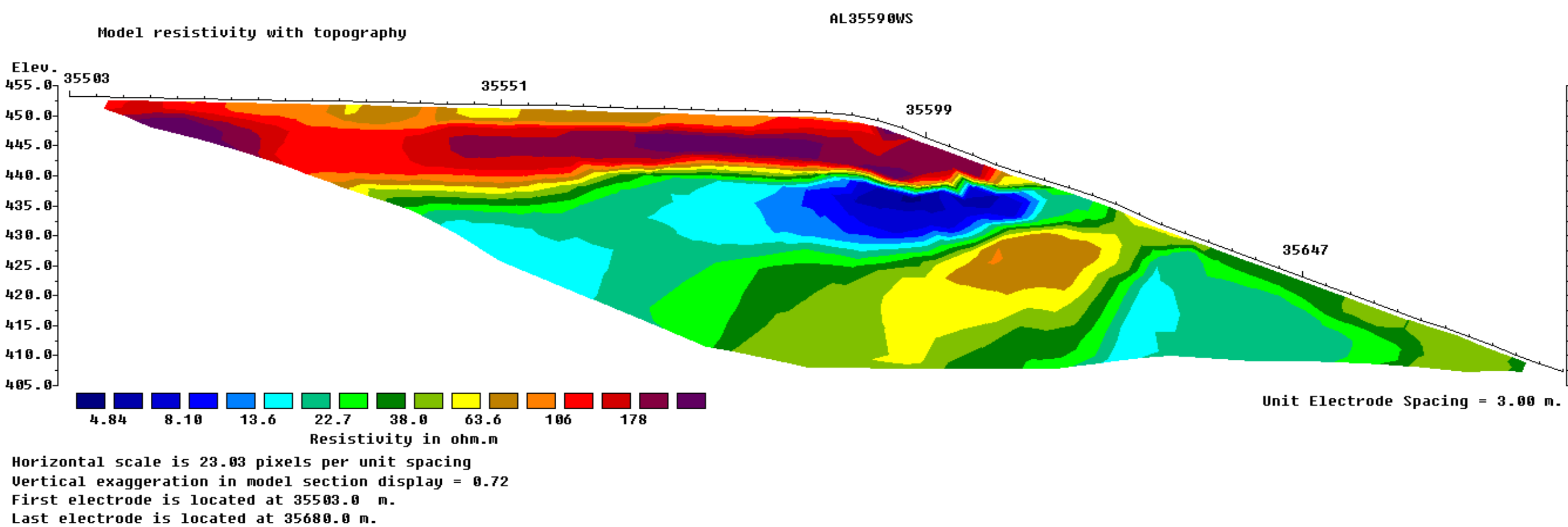
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows vertical changes in resistivity values and lower values in the middle layer of the profile.

CH – 35590 Along SRT



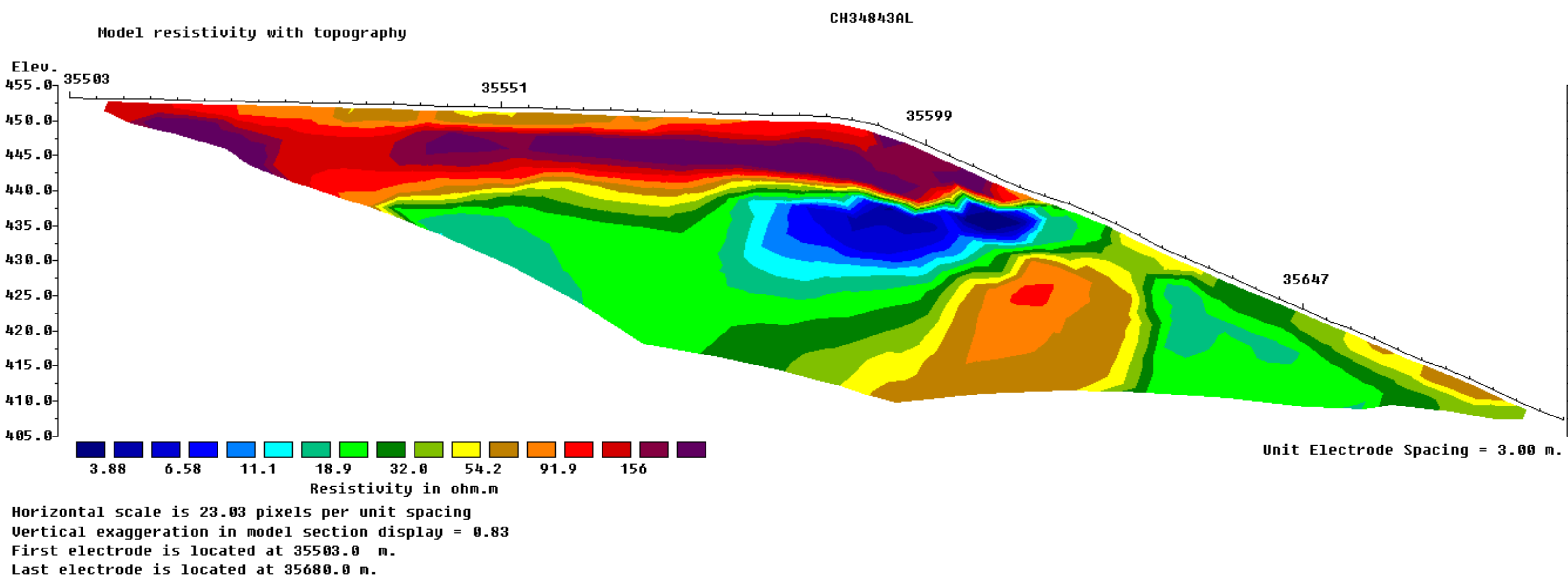
SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 1100m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 2300m/s and is likely to correspond to highly weathered rock.

CH – 35590 Along ERT – WS



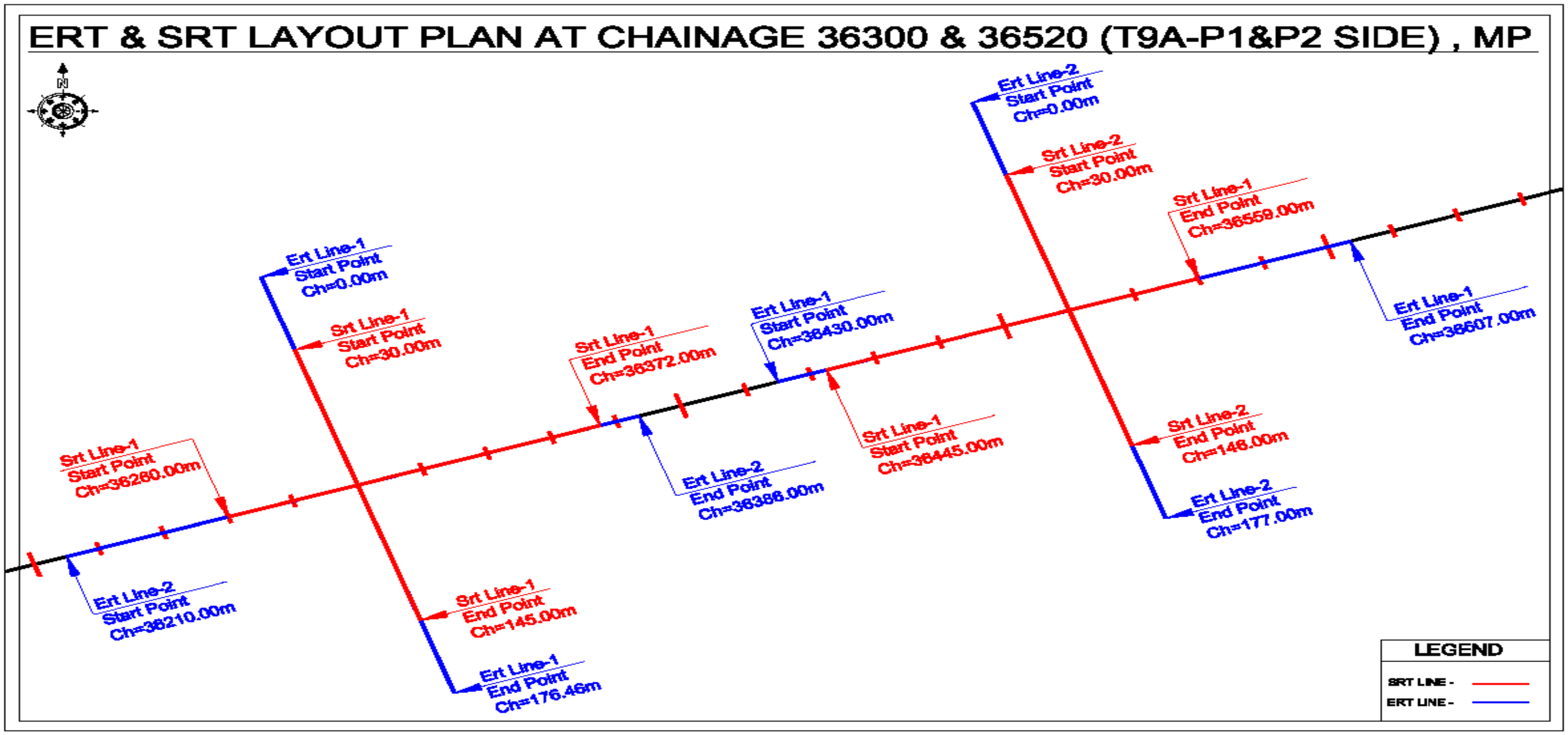
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the center of the profile.

CH – 35590 Along ERT – W

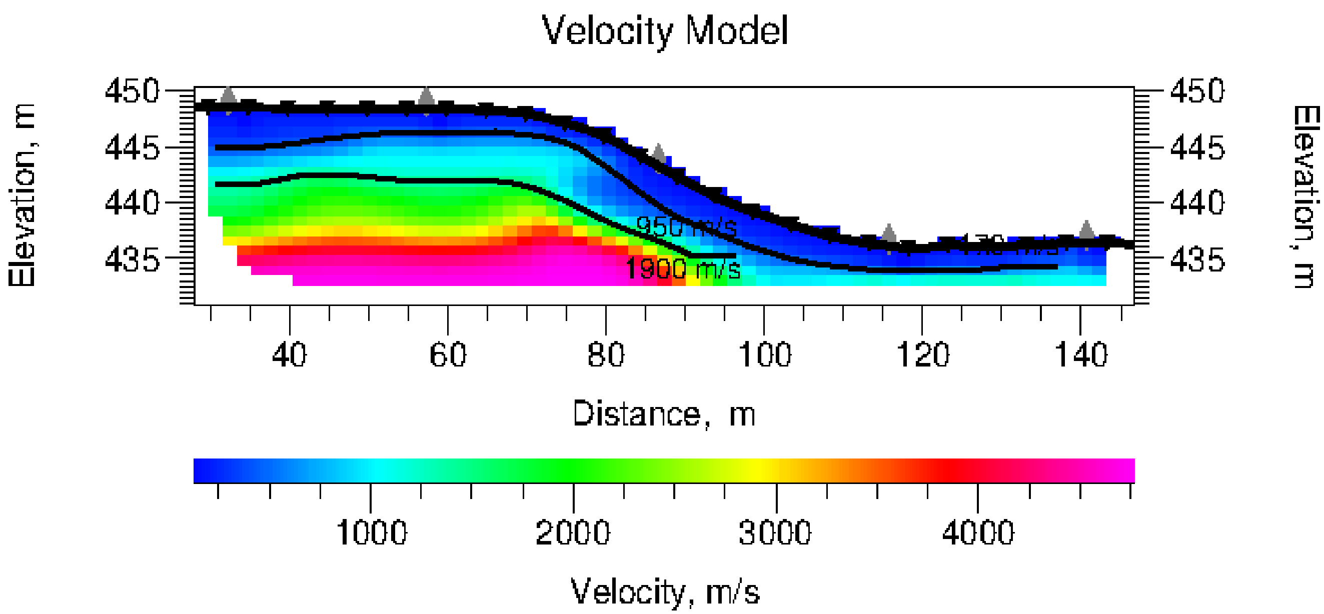


Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the center of the profile.

ERT & SRT LAYOUT PLAN AT CHAINAGE 36300

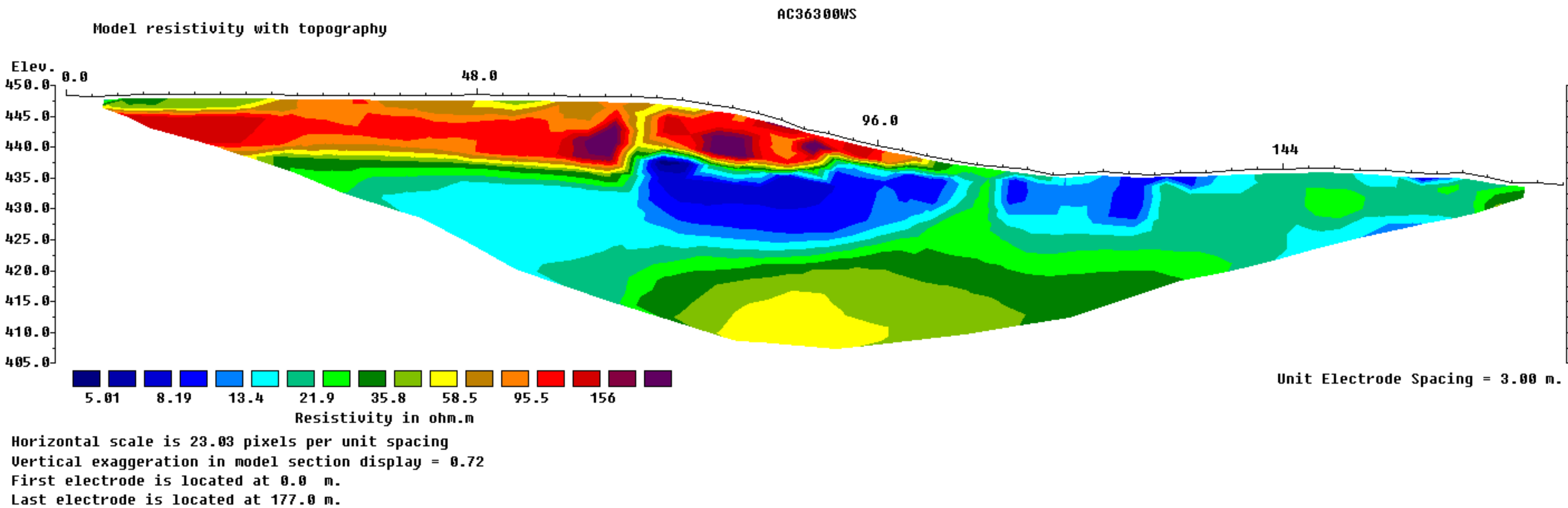


CH – 36300 Across SRT



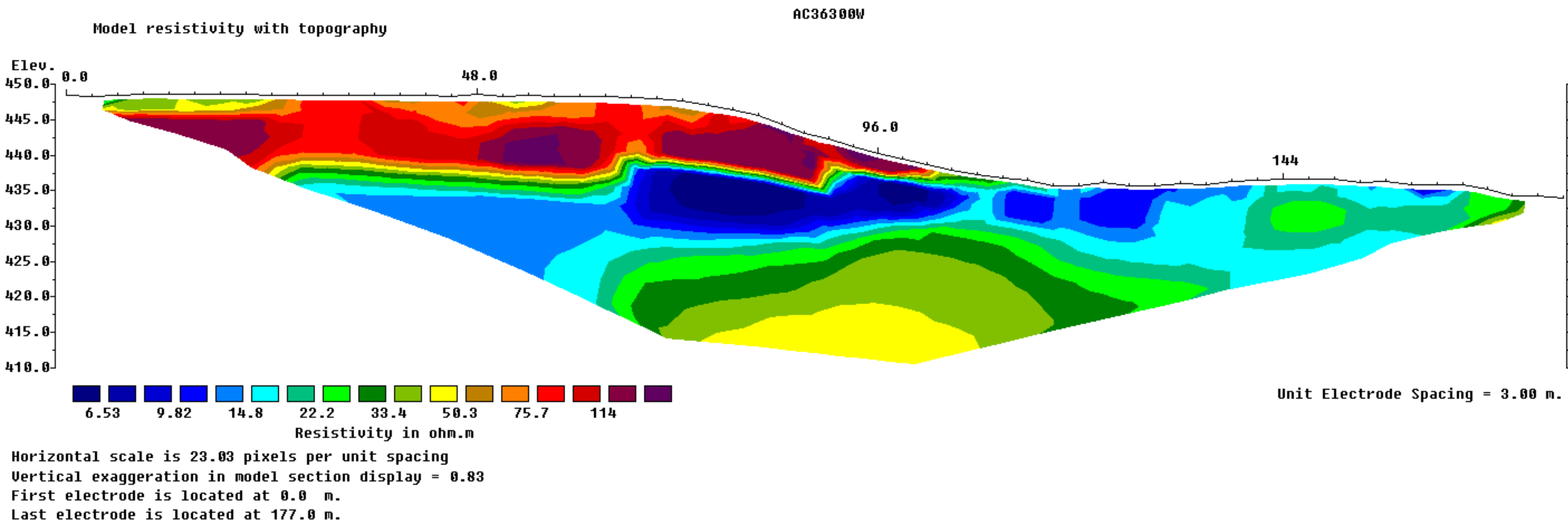
SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 950m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 1900m/s and is likely to correspond to highly weathered rock.

CH – 36300 Across ERT – WS



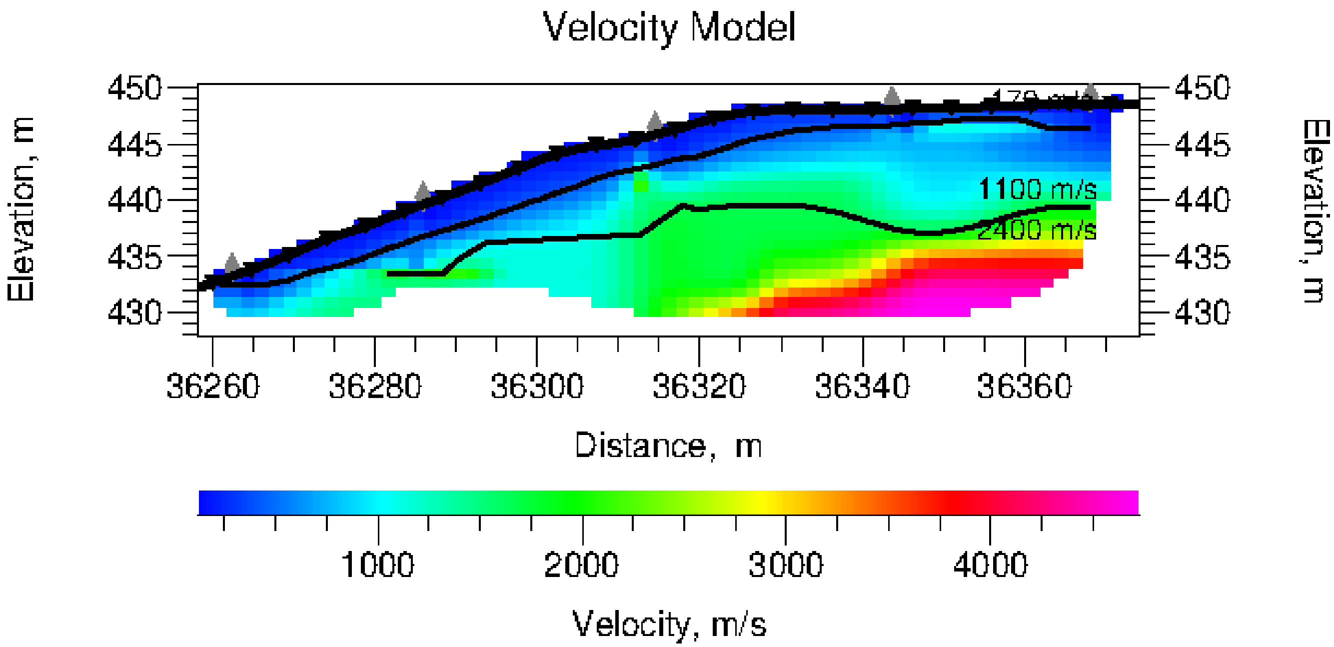
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the center of the profile.

CH – 36300 Across ERT – W



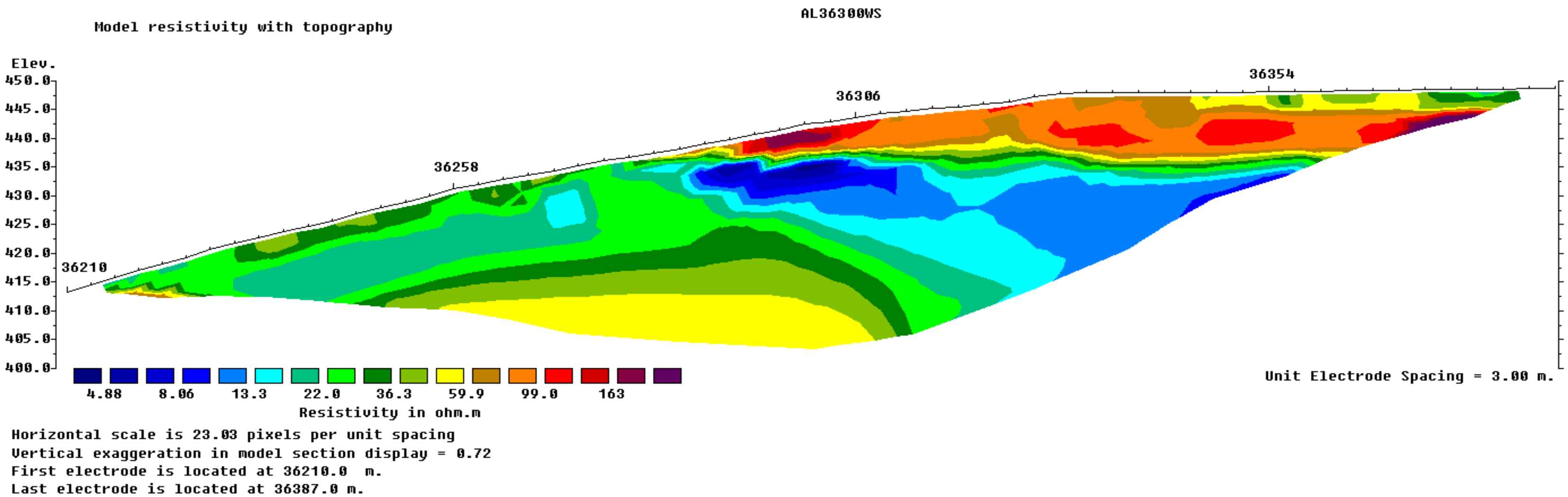
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the center of the profile.

CH – 36300 Along ERT – WS



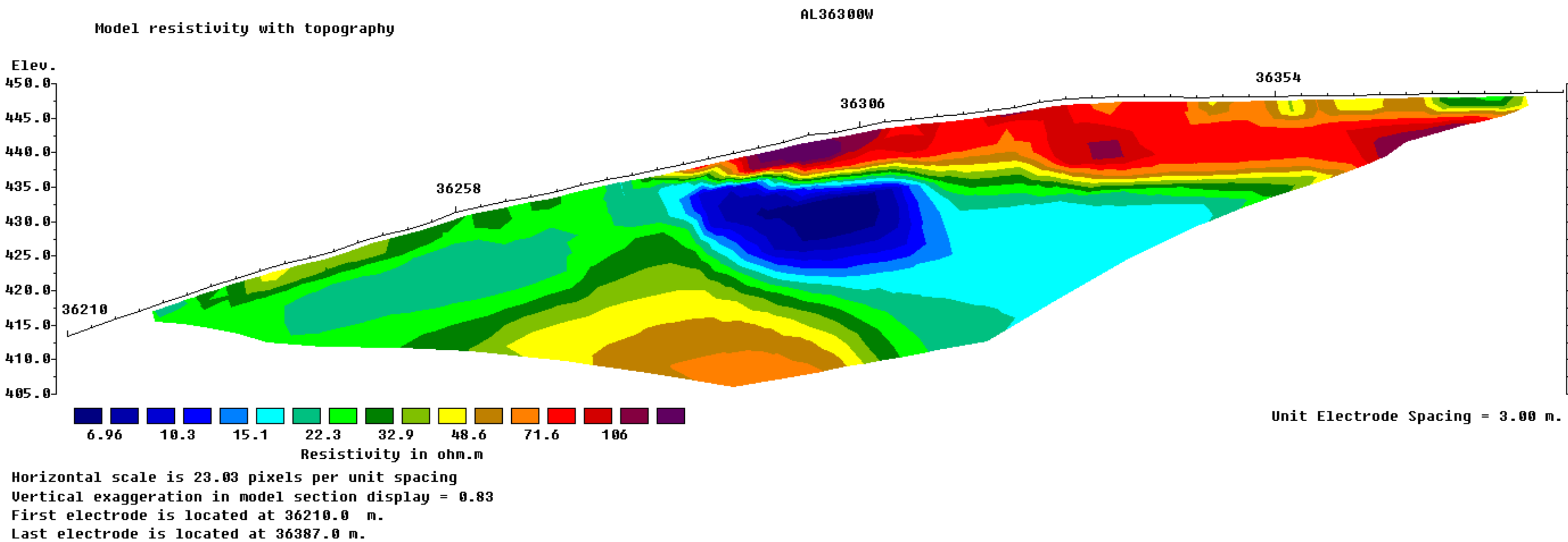
SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 1100m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 2400m/s and is likely to correspond to highly weathered rock.

CH – 36300 ALong ERT – WS



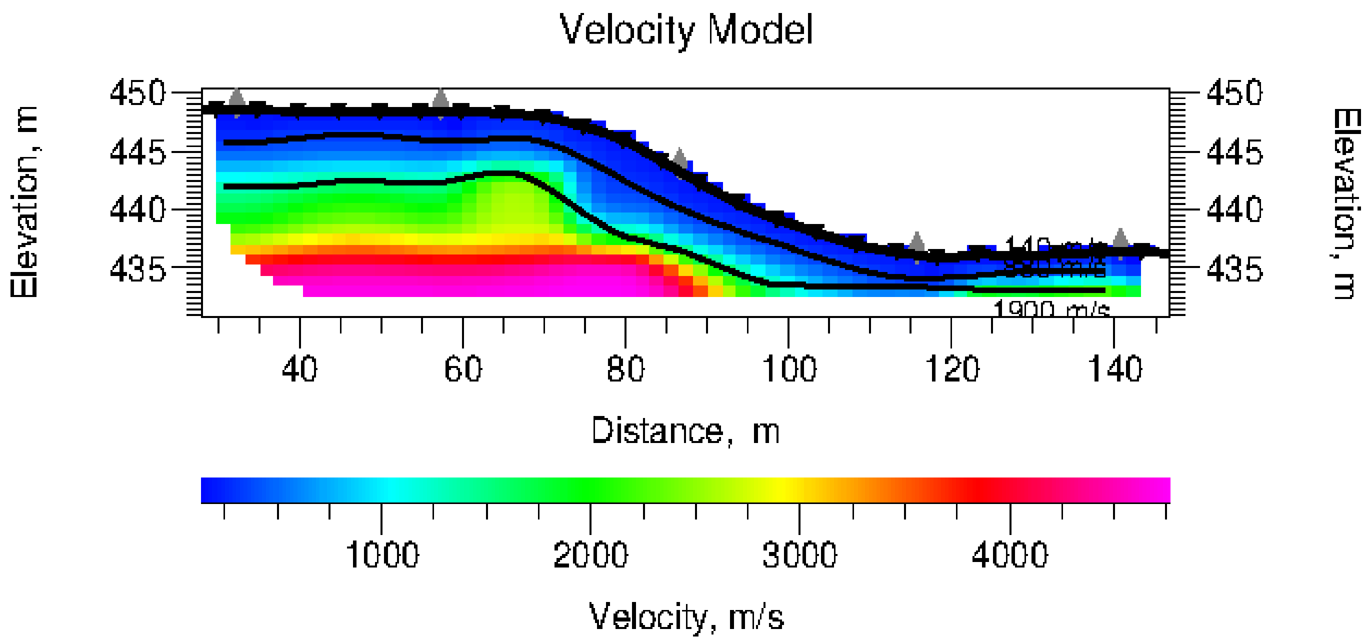
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the center-right of the profile.

CH – 36300 ALong ERT – W



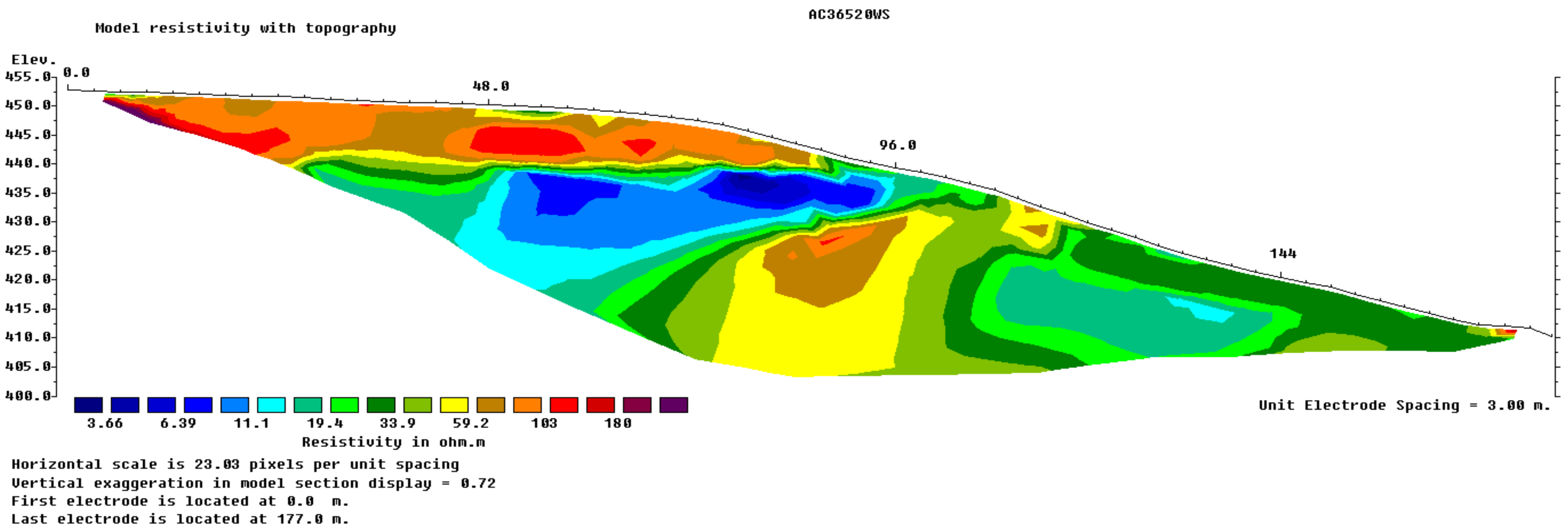
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the center-right of the profile.

CH – 36520 Across SRT



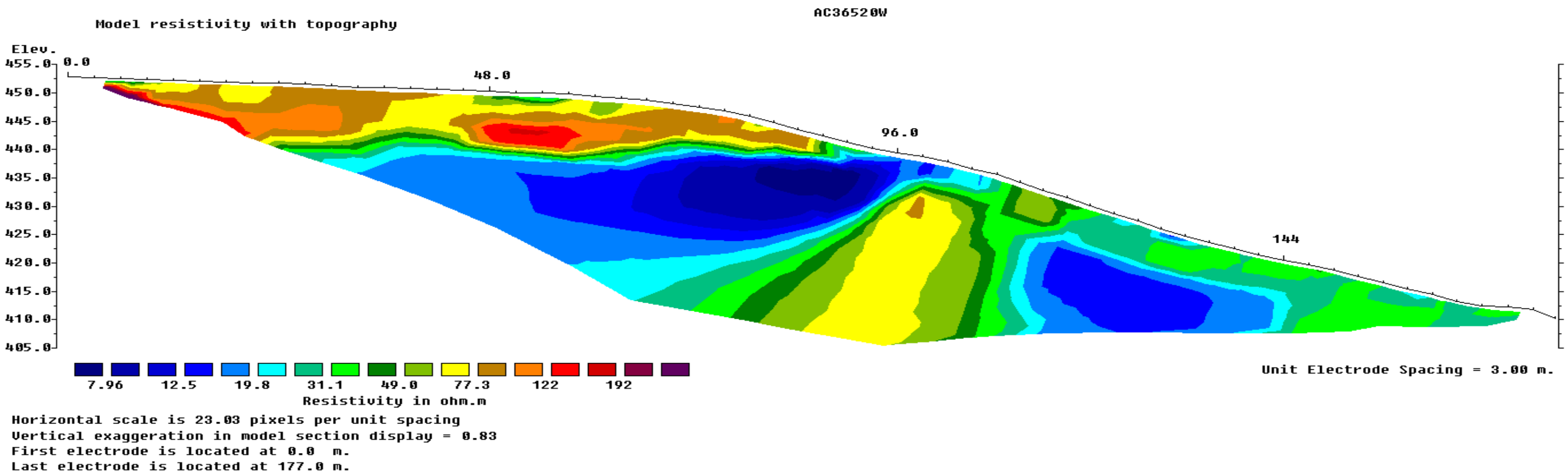
SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 880m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 1900m/s and is likely to correspond to highly weathered rock.

CH – 36520 Across ERT - WS



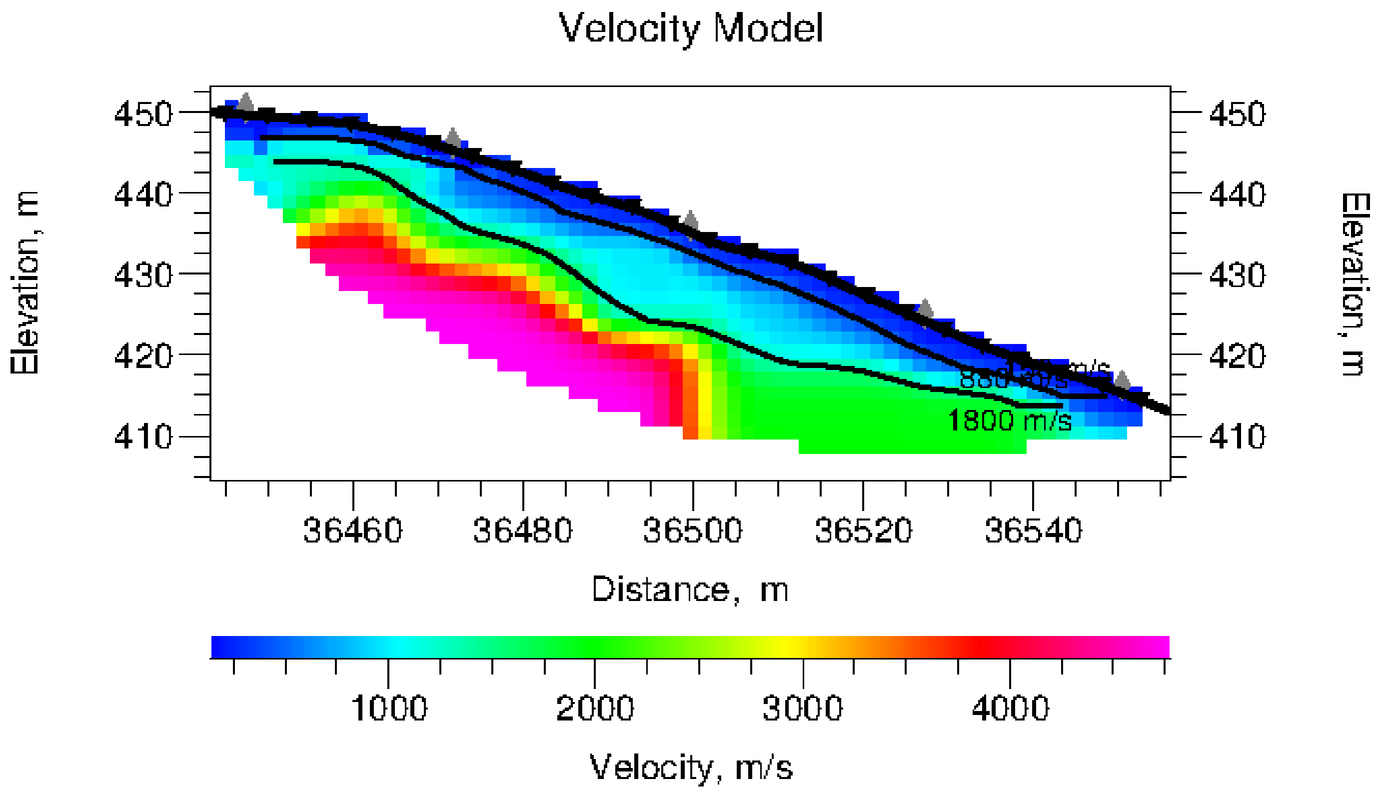
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the center-left and right of the profile.

CH – 36520 Across ERT - W



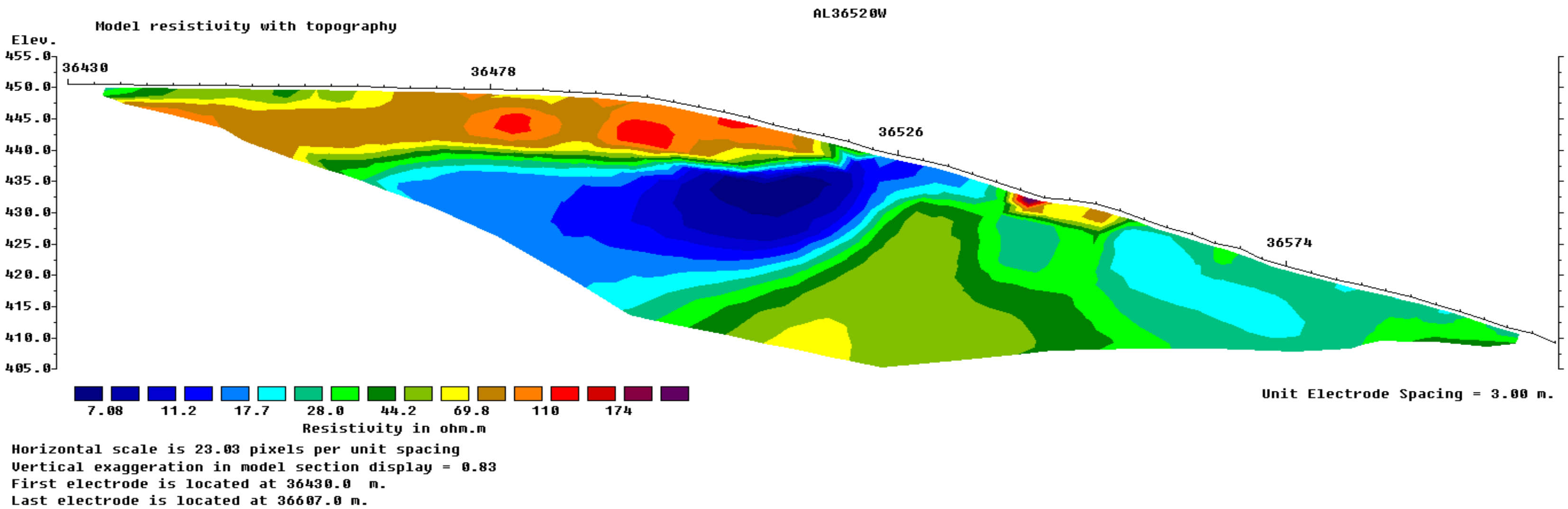
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the center-left and right of the profile.

CH – 36520 Along SRT



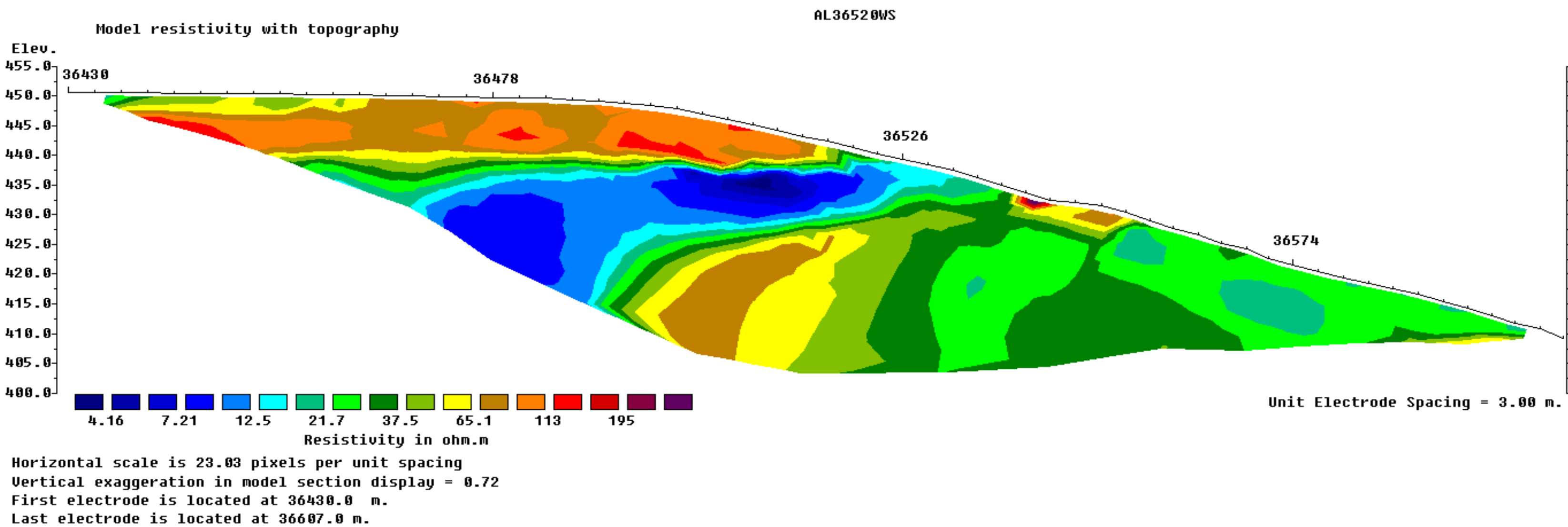
SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 880m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 1800m/s and is likely to correspond to highly weathered rock.

CH – 36520 Along ERT - W



Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the center-left and right of the profile.

CH – 36520 Along ERT - WS



Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the center-left and right of the profile.

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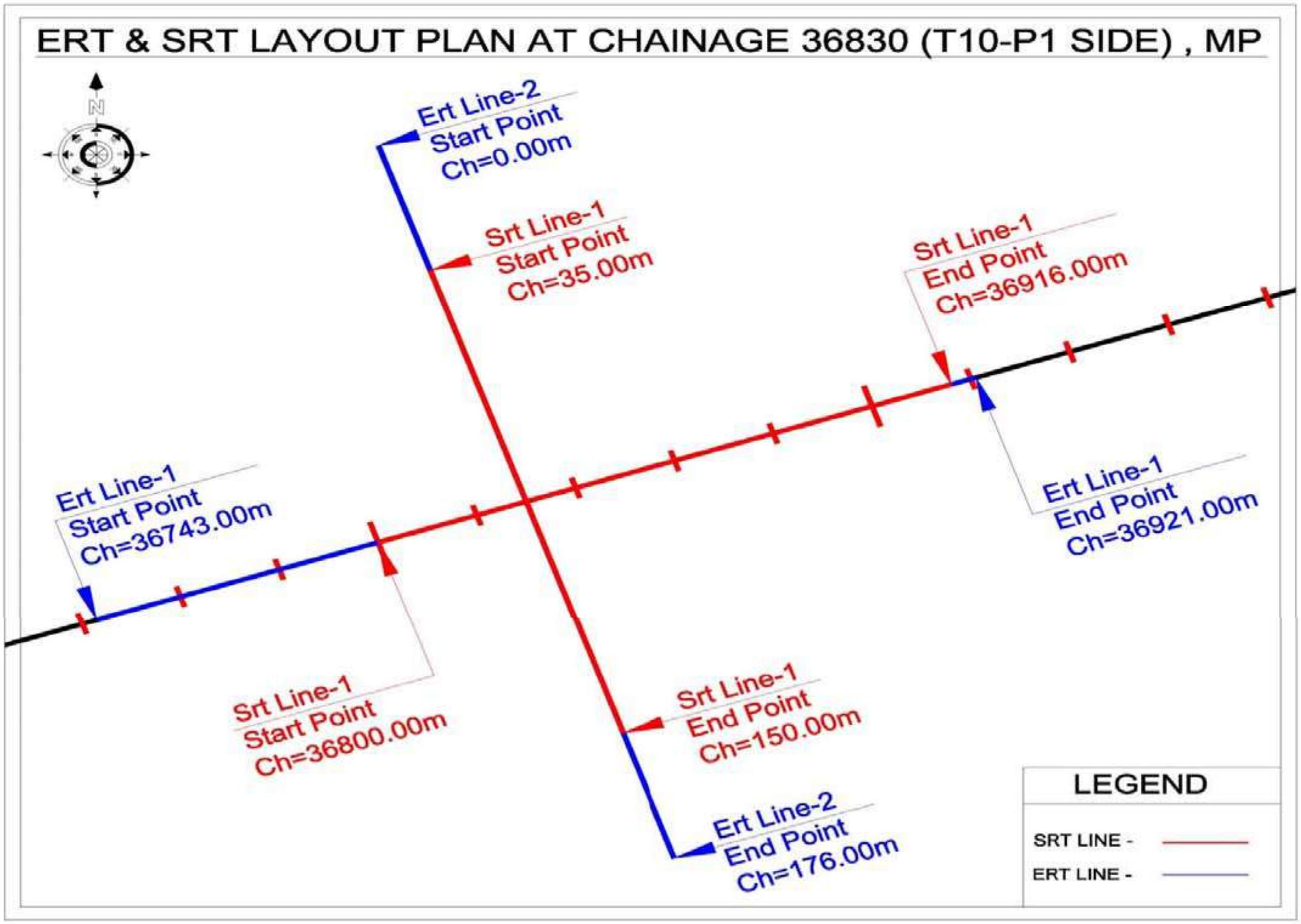
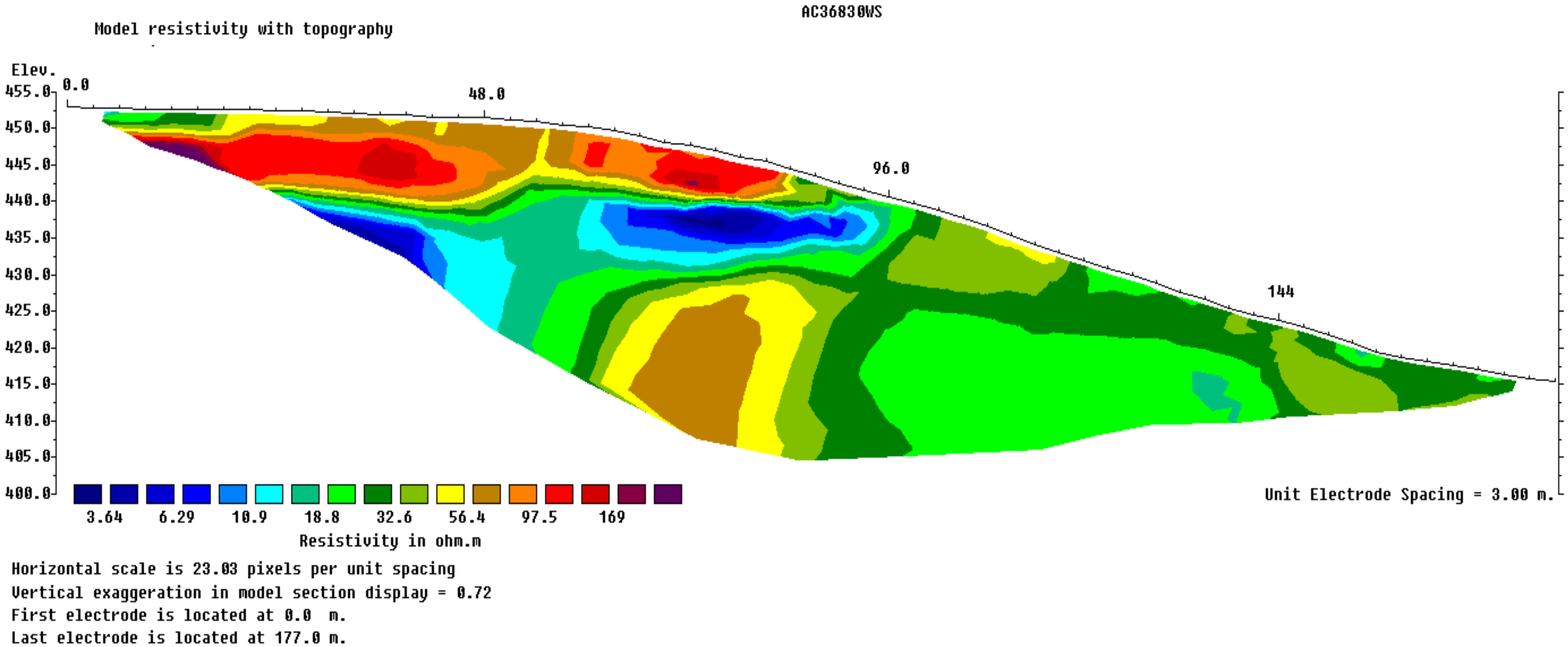
ERT & SRT LAYOUT PLAN AT CHAINAGE 36380 (T 10-P1 SIDE)

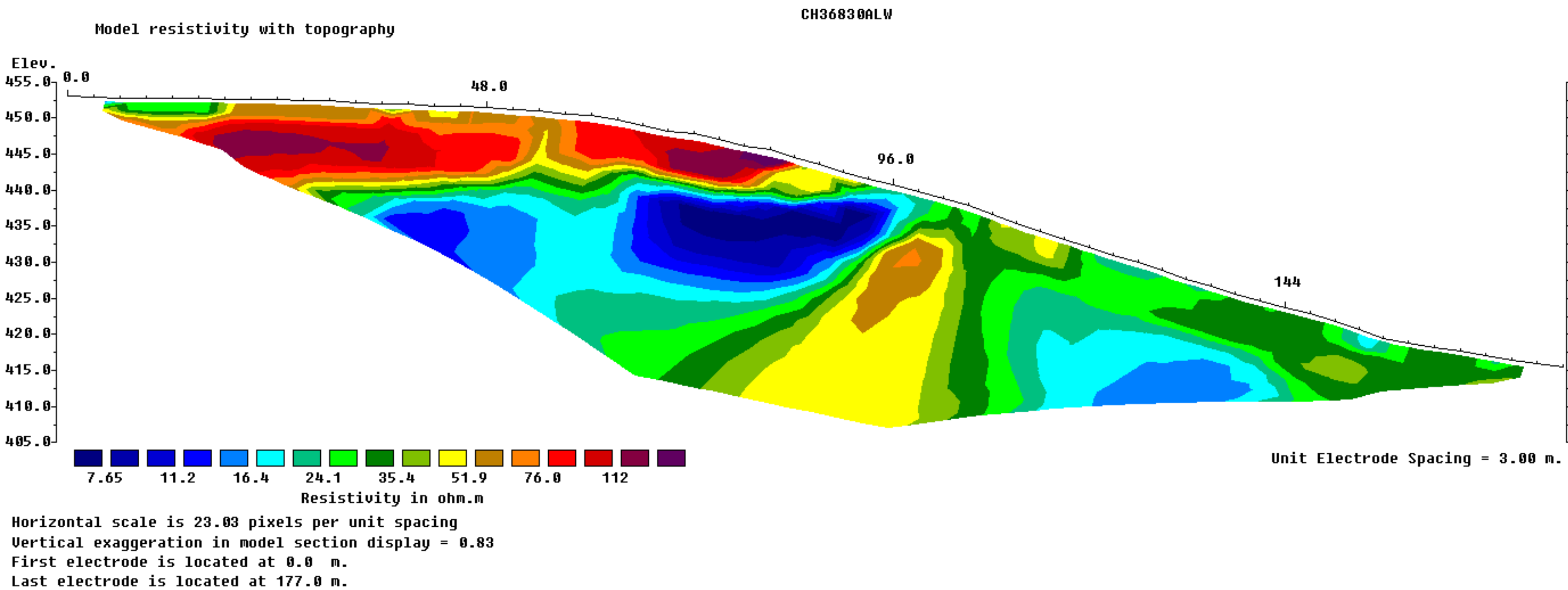


CHAINAGE 36380 (T 10-P1 SIDE) ACROSS – ERT WS



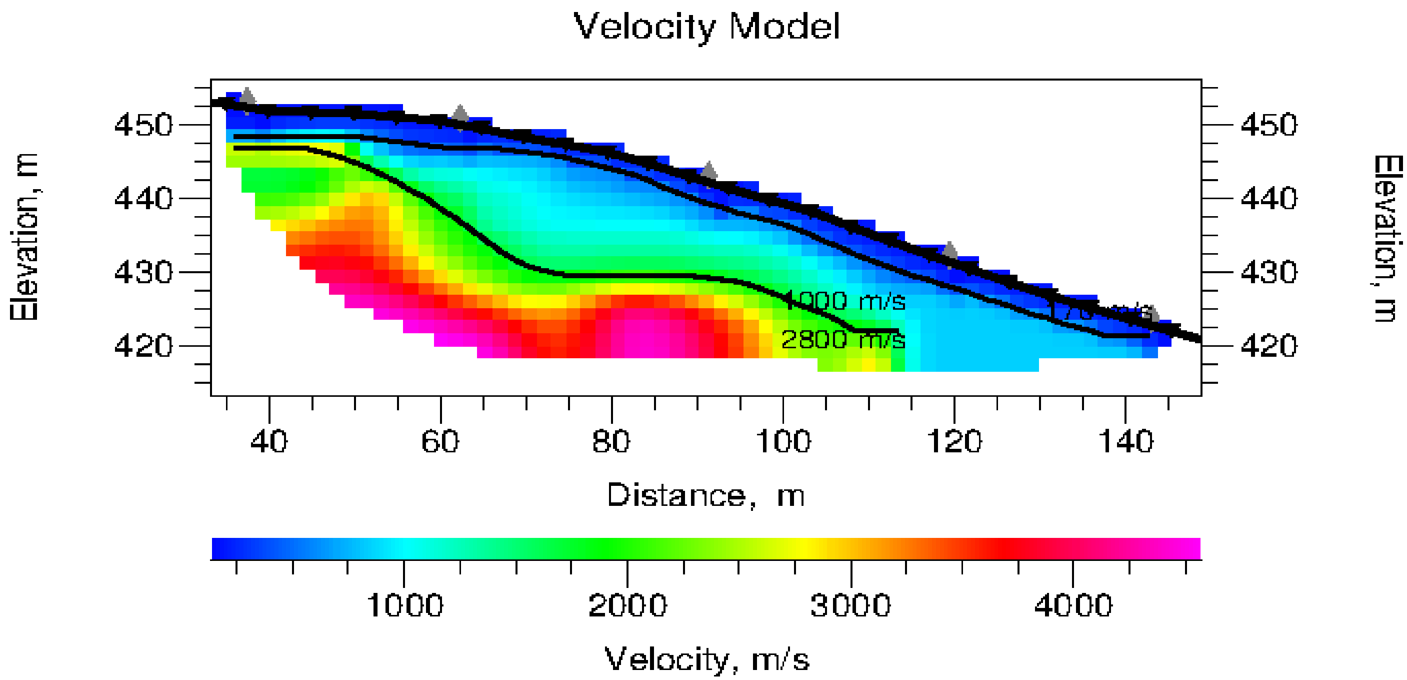
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the center-left of the profile.

CHAINAGE 36380 (T 10-P1 SIDE) ACROSS – ERT W



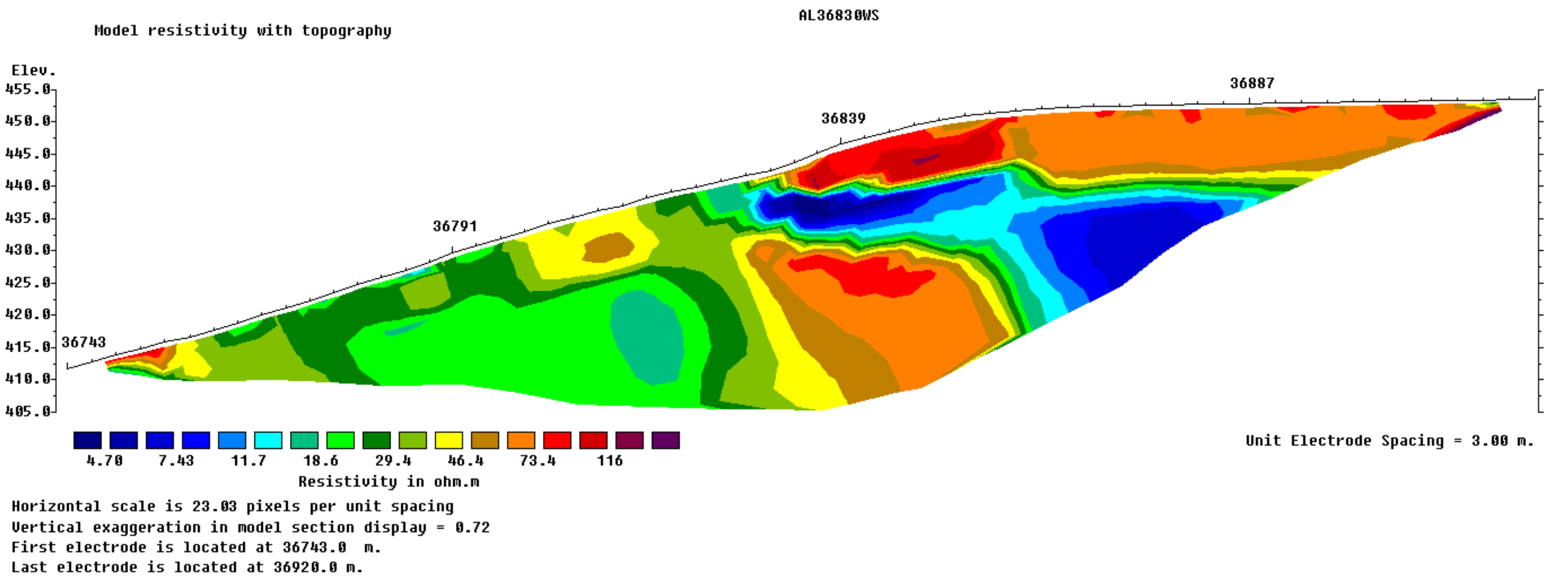
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the center-left and right of the profile.

CHAINAGE 36380 (T 10-P1 SIDE) ACROSS – SRT



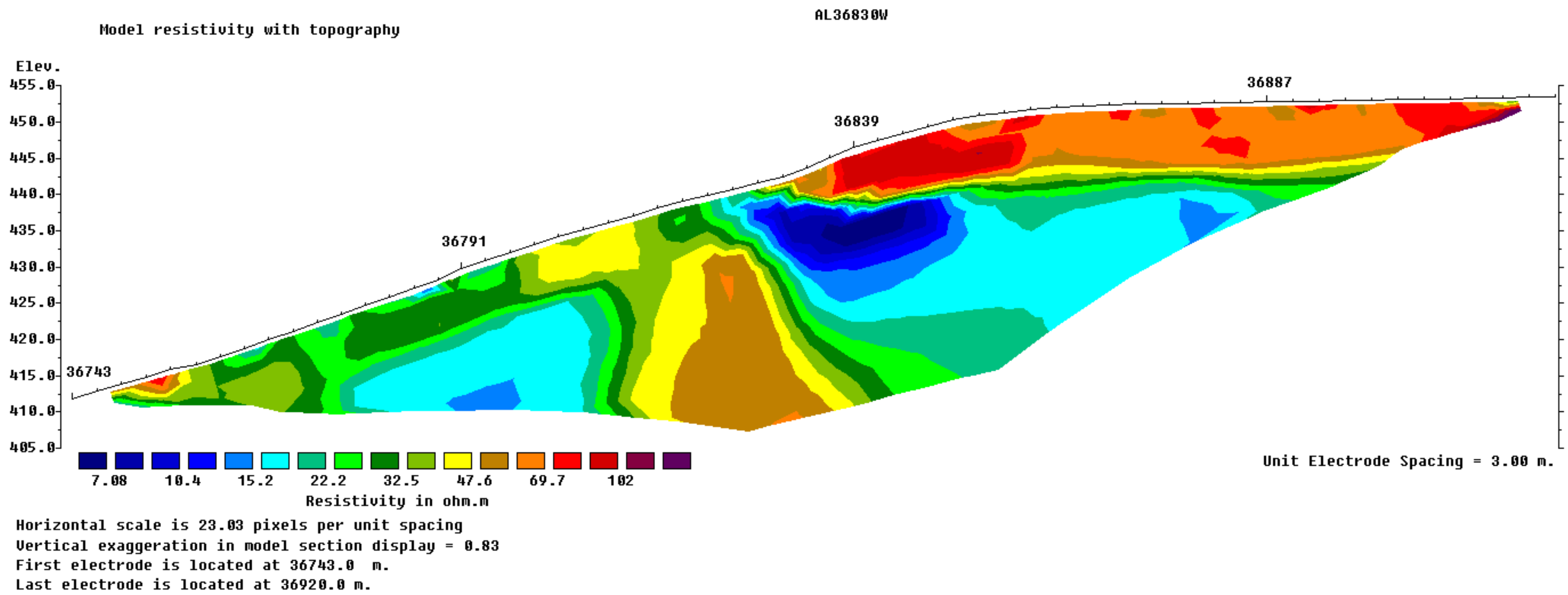
SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 1000m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 2800m/s and is likely to correspond to highly weathered rock.

CHAINAGE 36380 (T 10-P1 SIDE) ALONG – ERT WS



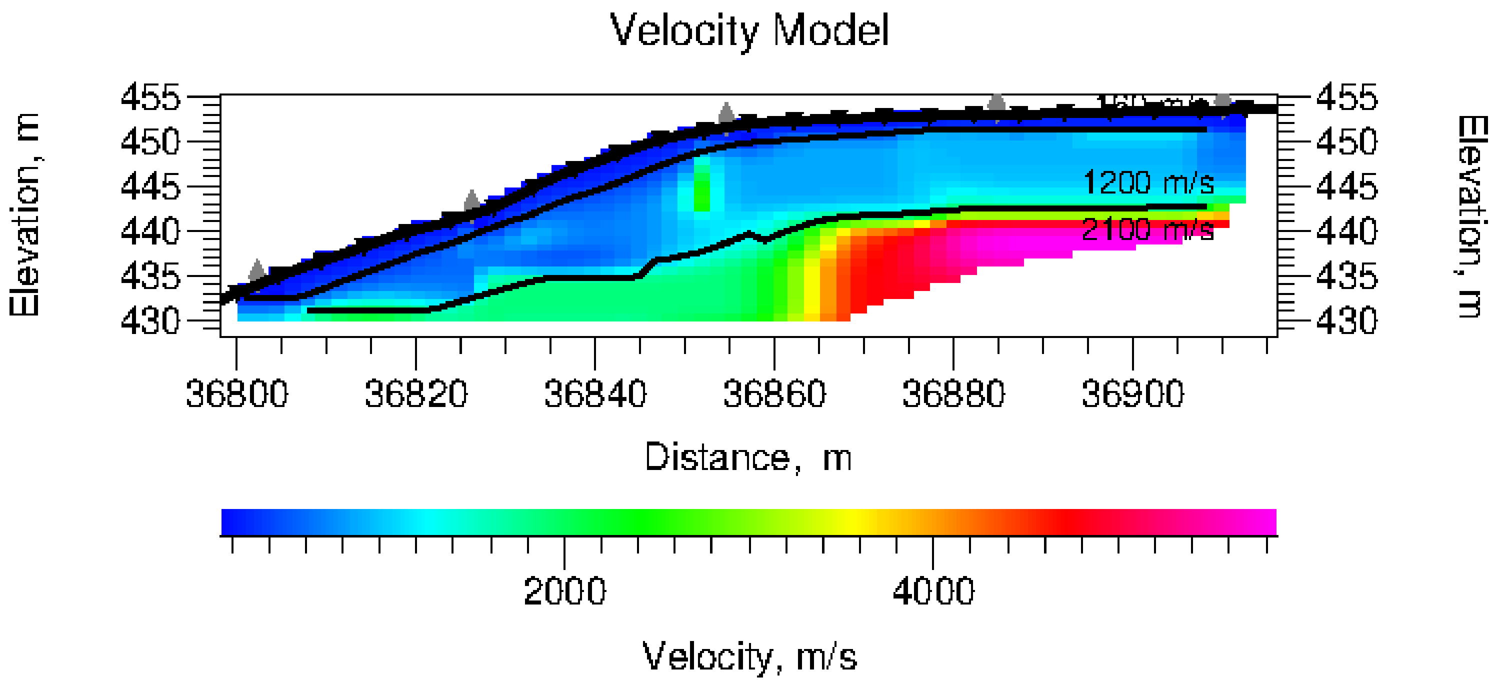
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the center-right of the profile.

CHAINAGE 36380 (T 10-P1 SIDE) ALONG – ERT W



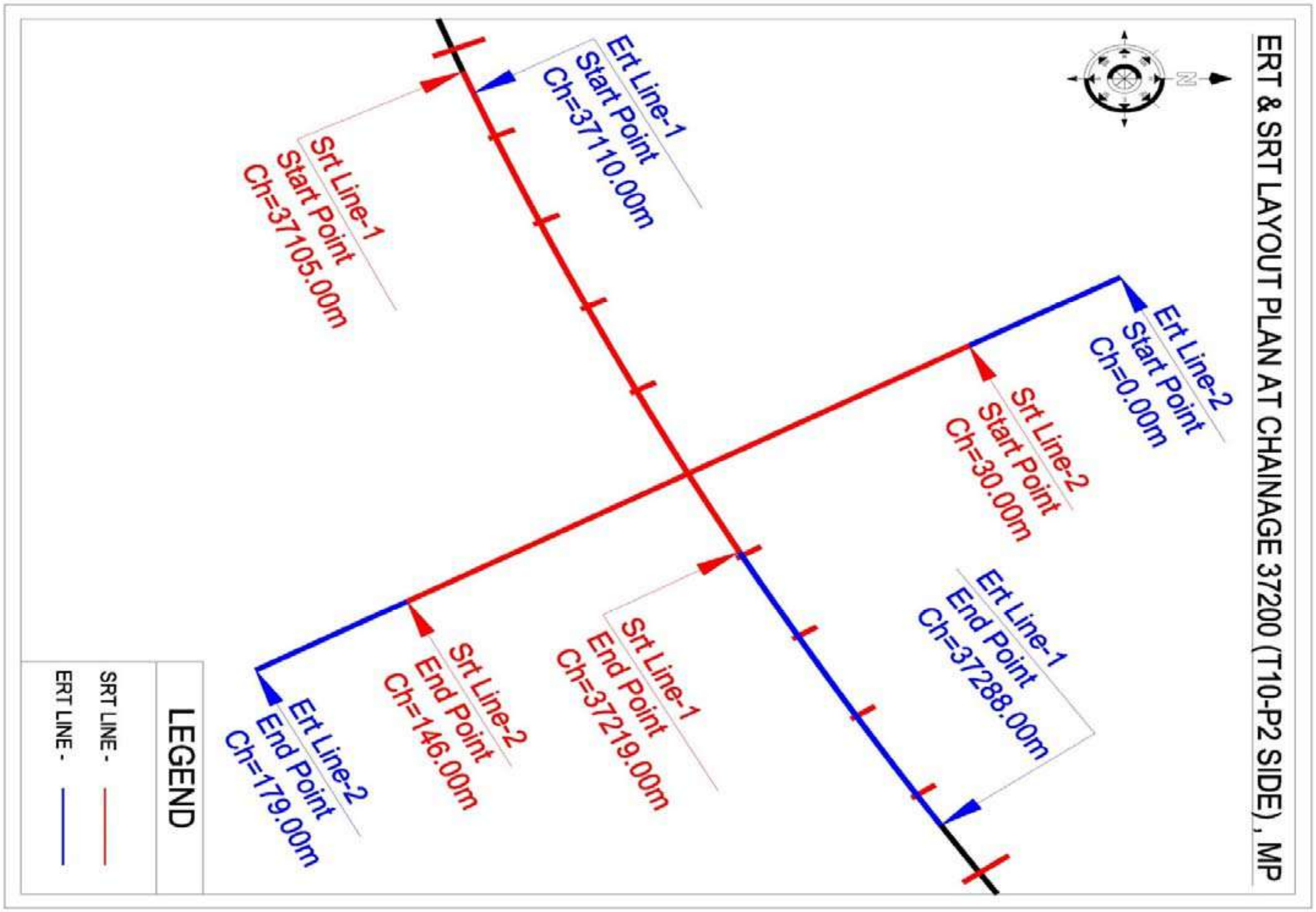
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the center-right of the profile.

CHAINAGE 36380 (T 10-P1 SIDE) ALONG – SRT

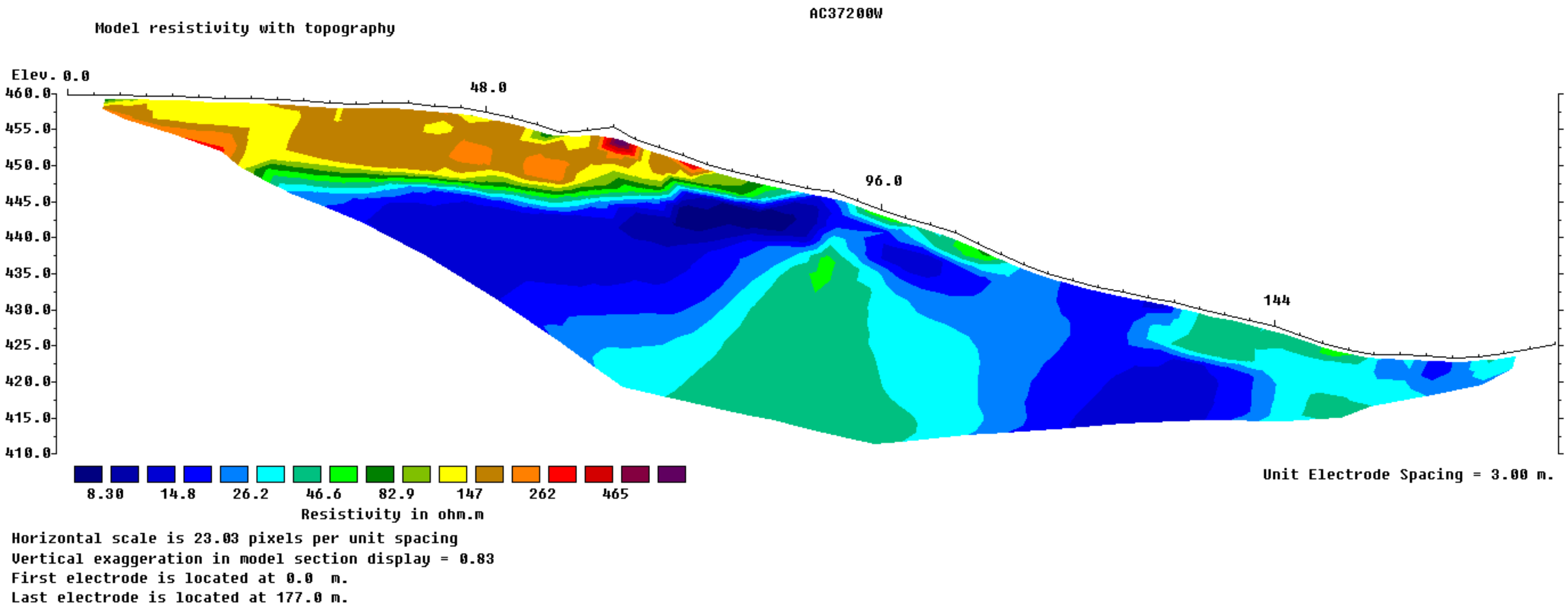


SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 1200m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 2100m/s and is likely to correspond to highly weathered rock.

ERT & SRT LAYOUT PLAN AT CHAINAGE 37200 (T 10-P2 SIDE)

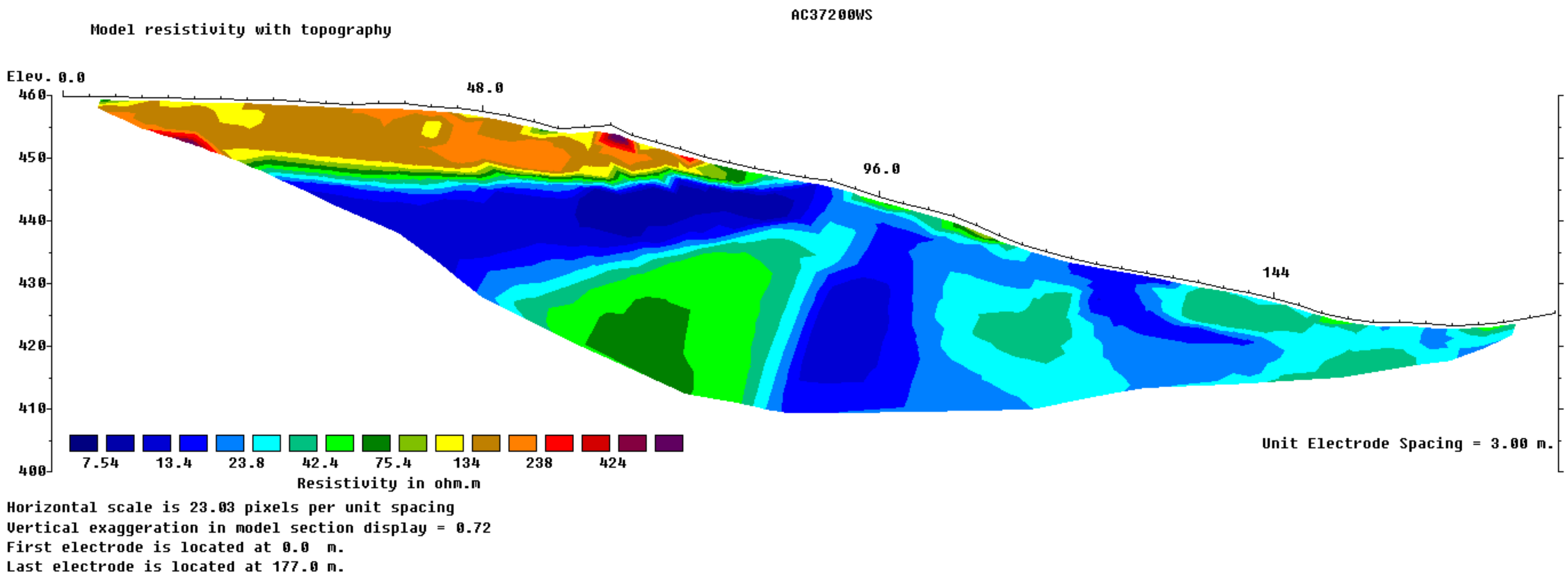


CHAINAGE 37200 (T 10-P2 SIDE)ACROSS- ERT W



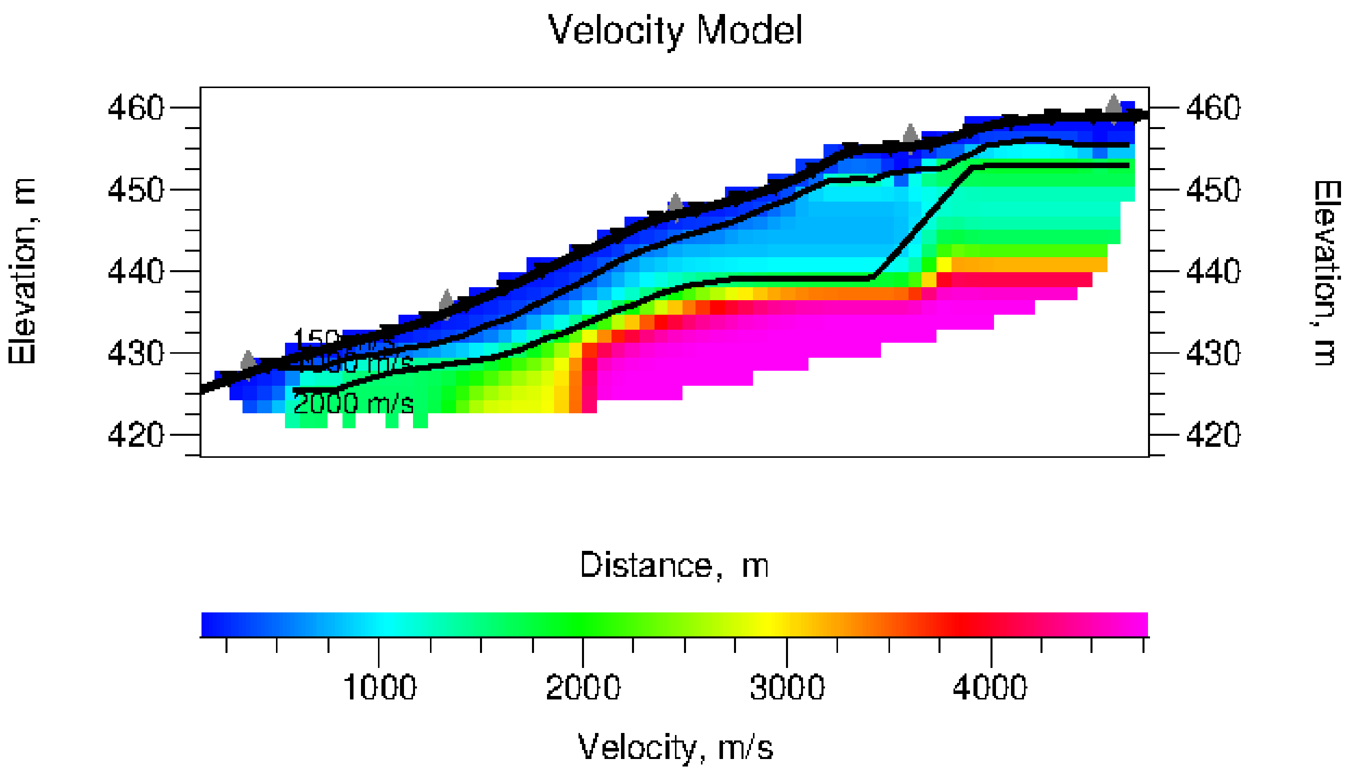
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values almost in the entire profile.

CHAINAGE 37200 (T 10-P2 SIDE)ACROSS- ERT WS



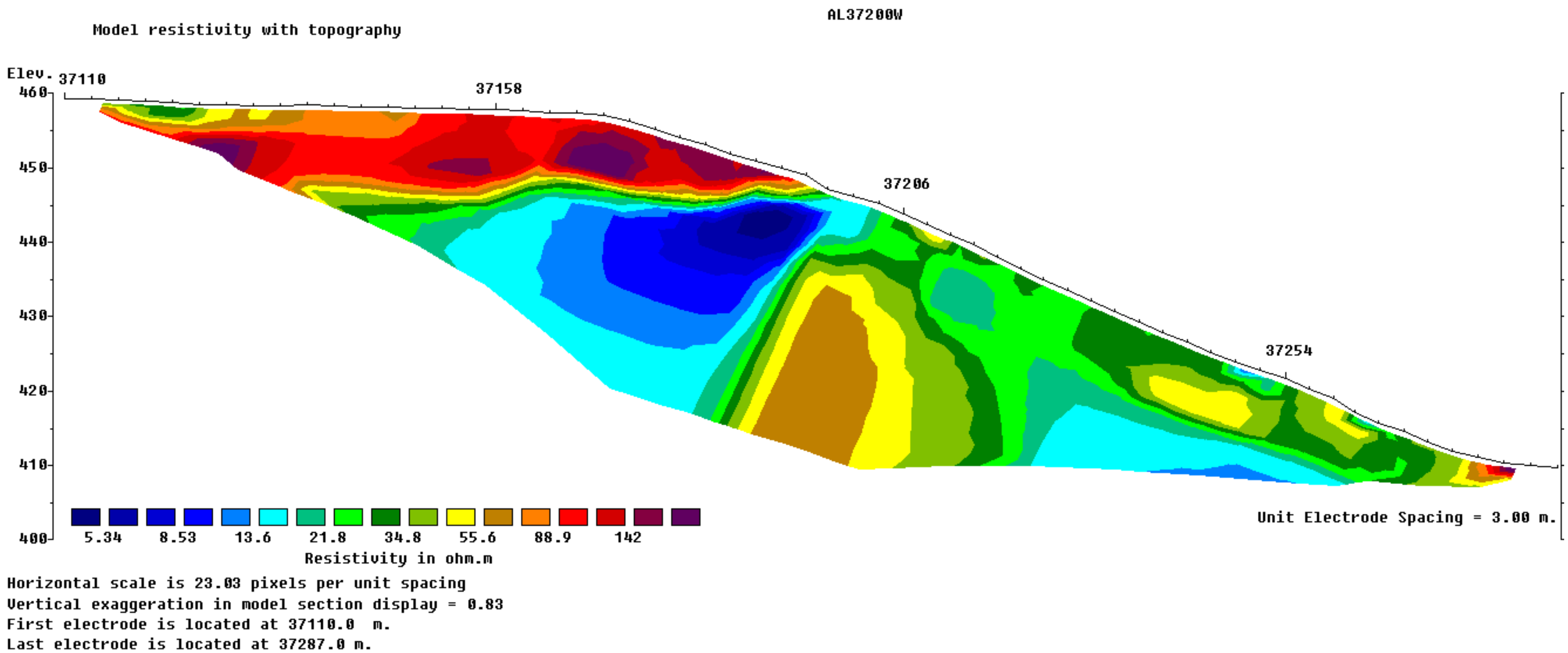
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values almost in the entire profile.

CHAINAGE 37200 (T 10-P2 SIDE)ACROSS- SRT



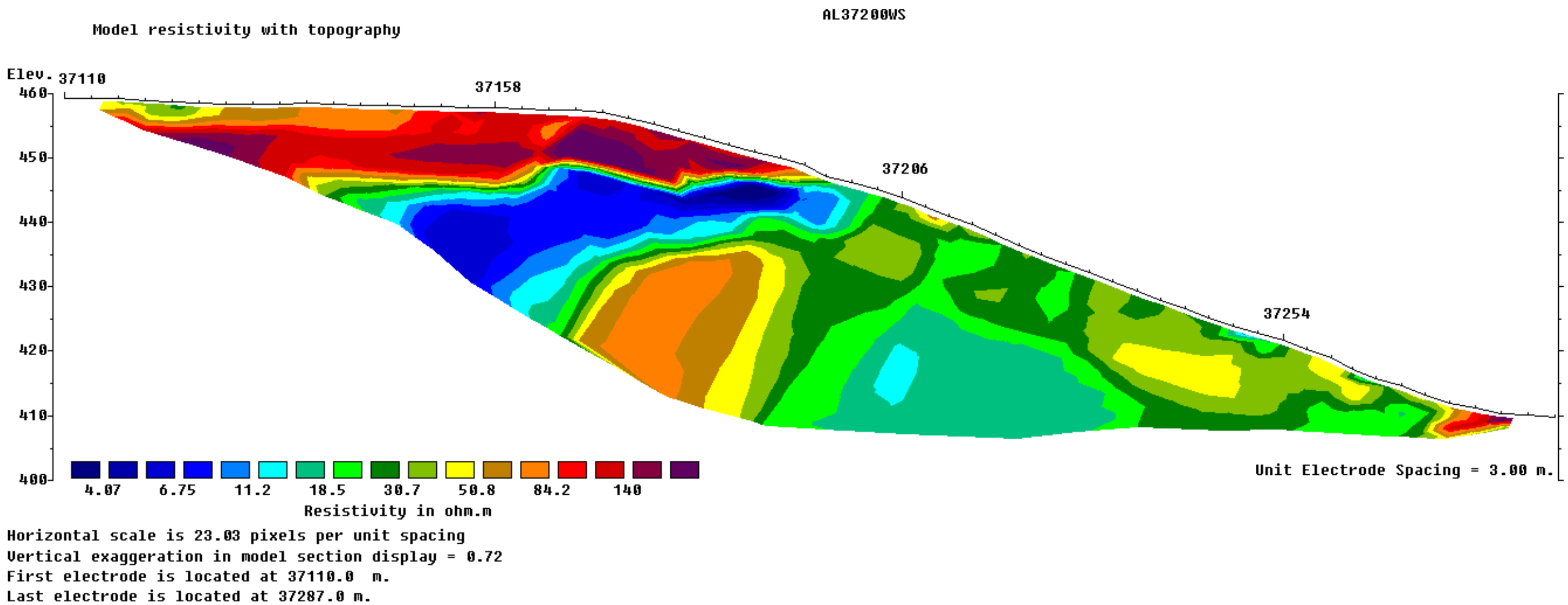
SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 1000m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 2000m/s and is likely to correspond to highly weathered rock.

CHAINAGE 37200 (T 10-P2 SIDE)ALONG- ERT W



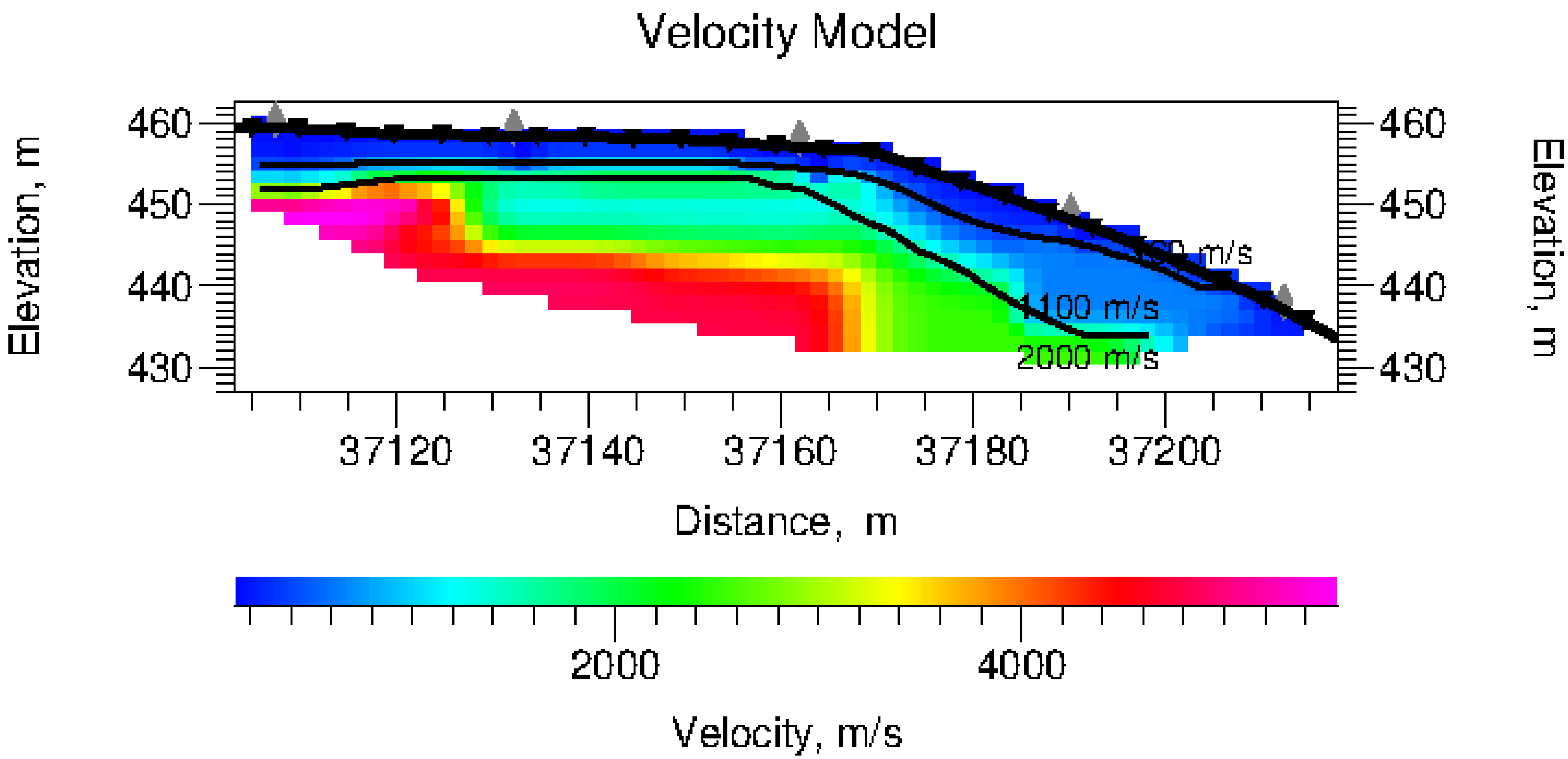
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the center-left of the profile.

CHAINAGE 37200 (T 10-P2 SIDE)ALONG- ERT WS



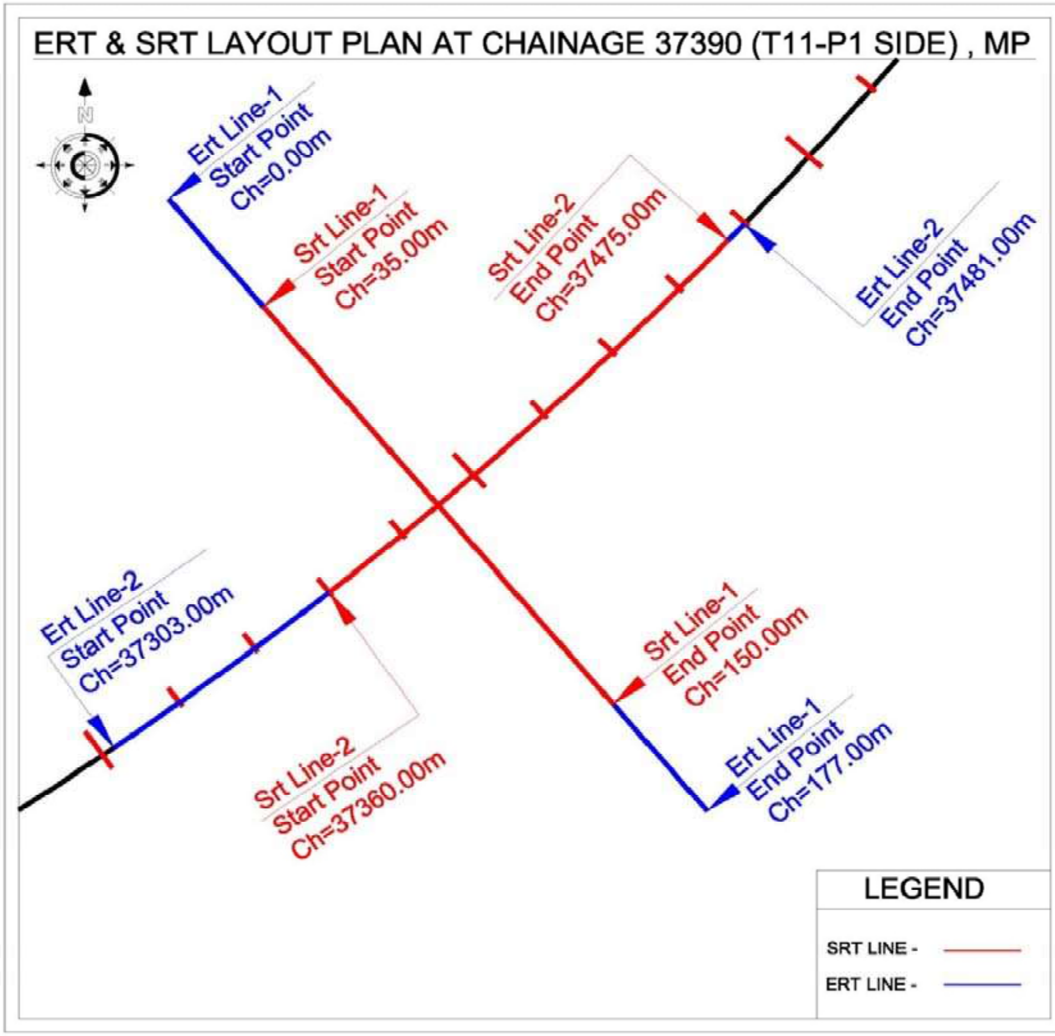
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the center-left of the profile.

CHAINAGE 37200 (T 10-P2 SIDE)ALONG- SRT

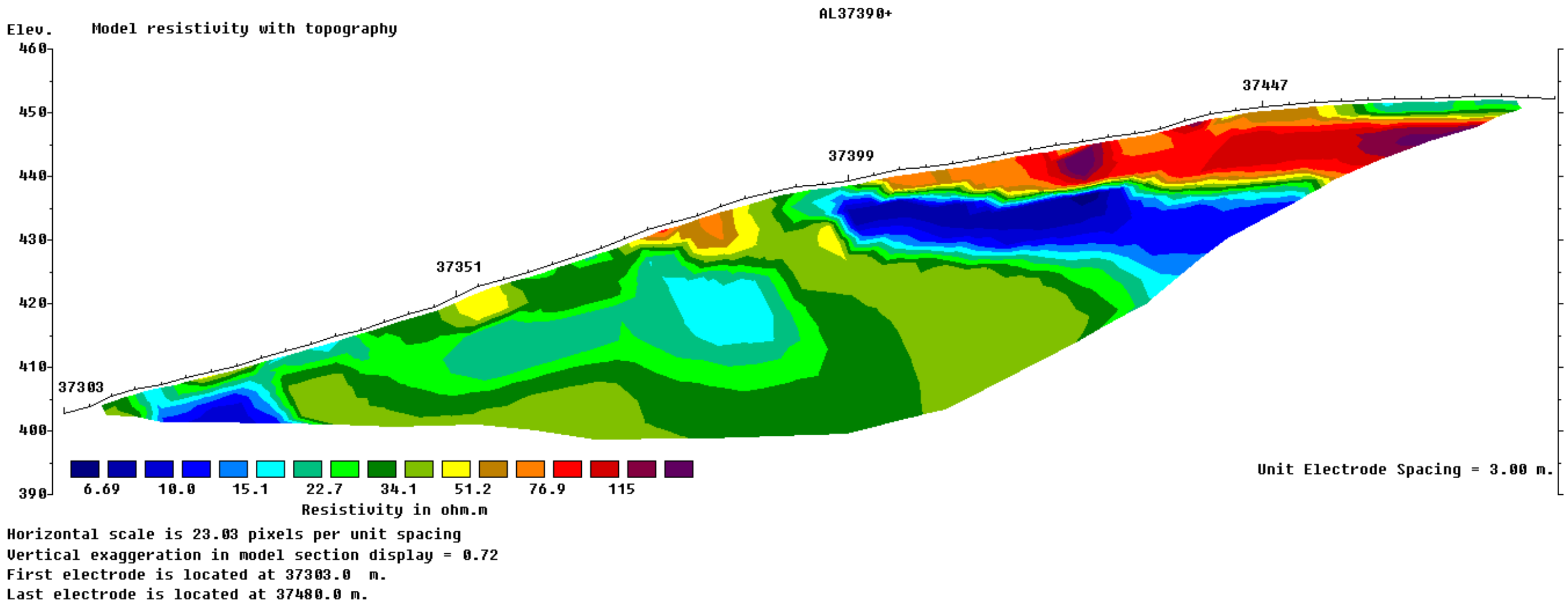


SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 1100m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 2000m/s and is likely to correspond to highly weathered rock.

ERT & SRT LAYOUT PLAN AT CHAINAGE 37390 (T 11-P1 SIDE)

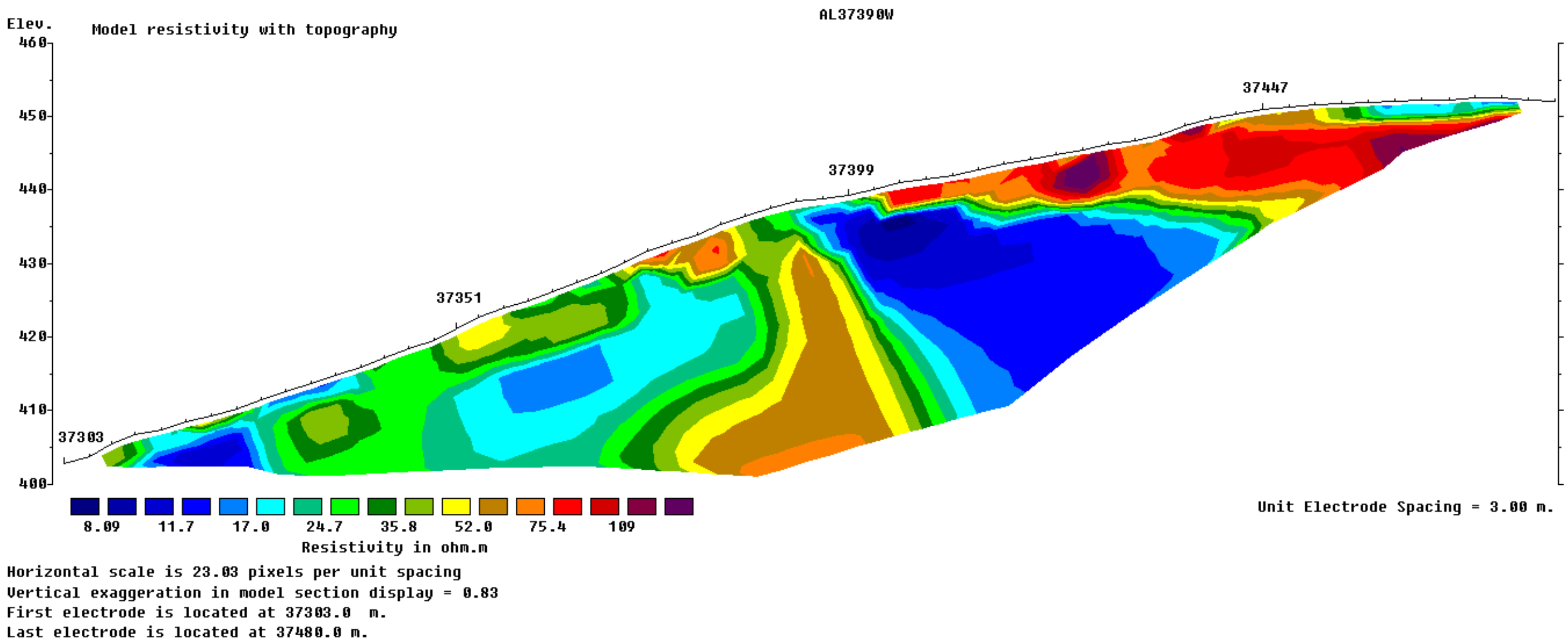


CHAINAGE 37390 (T 11-P1 SIDE) ALONG ERT- WS



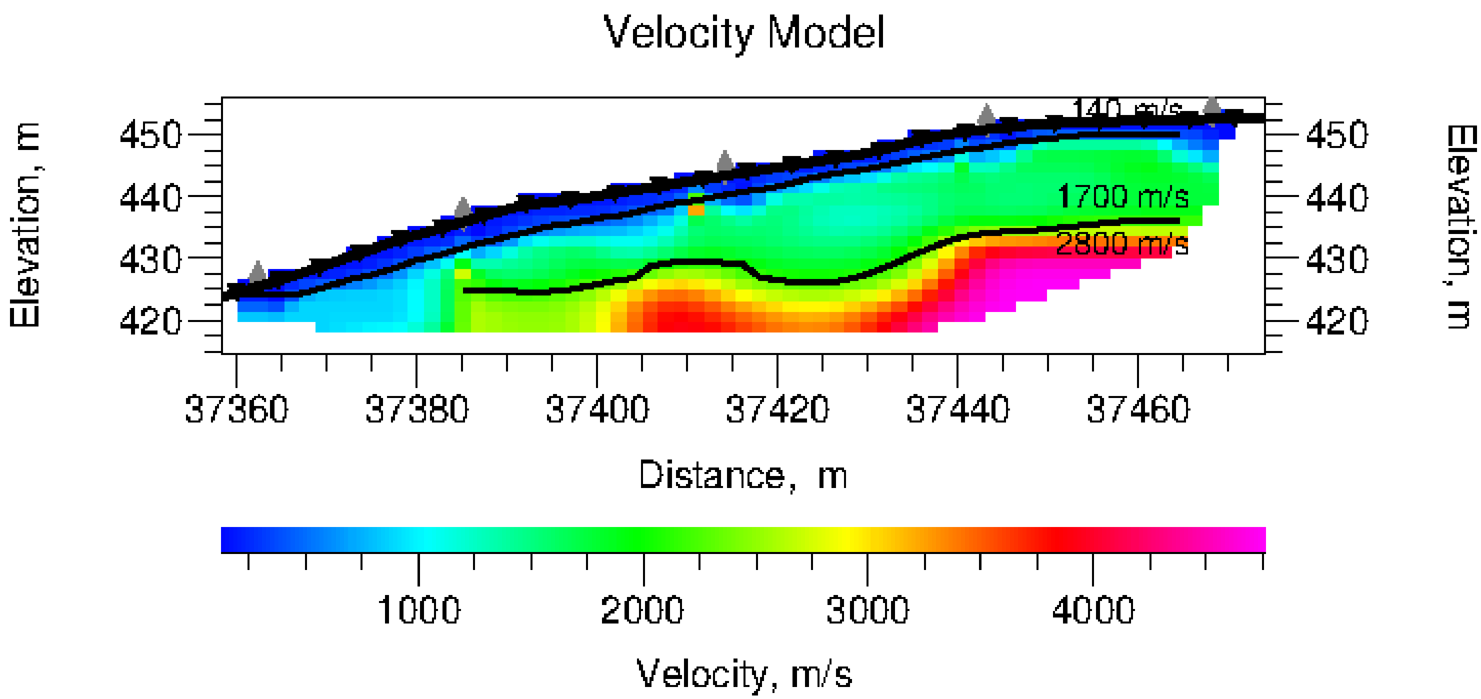
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the right of the profile.

CHAINAGE 37390 (T 11-P1 SIDE) ALONG ERT- W



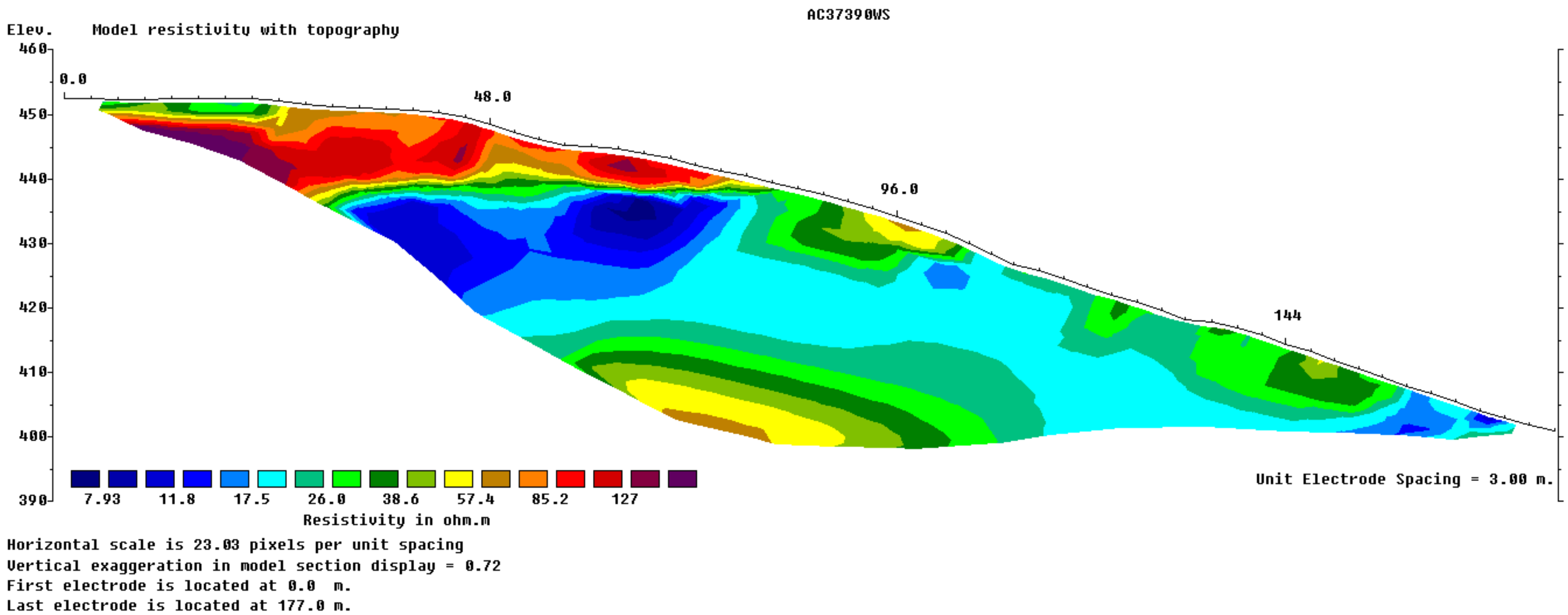
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the right of the profile.

CHAINAGE 37390 (T 11-P1 SIDE) ALONG SRT



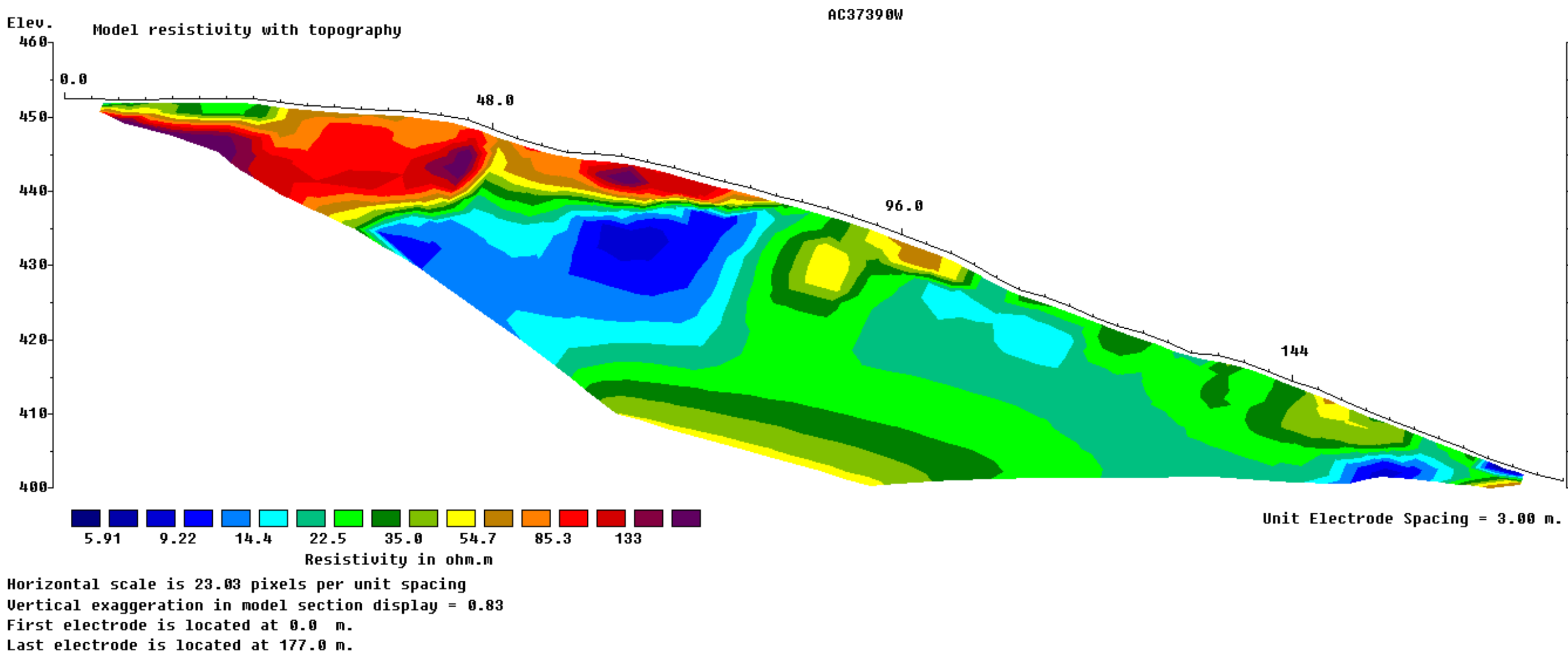
SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 1700m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 2800m/s and is likely to correspond to highly weathered rock.

CHAINAGE 37390 (T 11-P1 SIDE) ACROSS ERT- WS



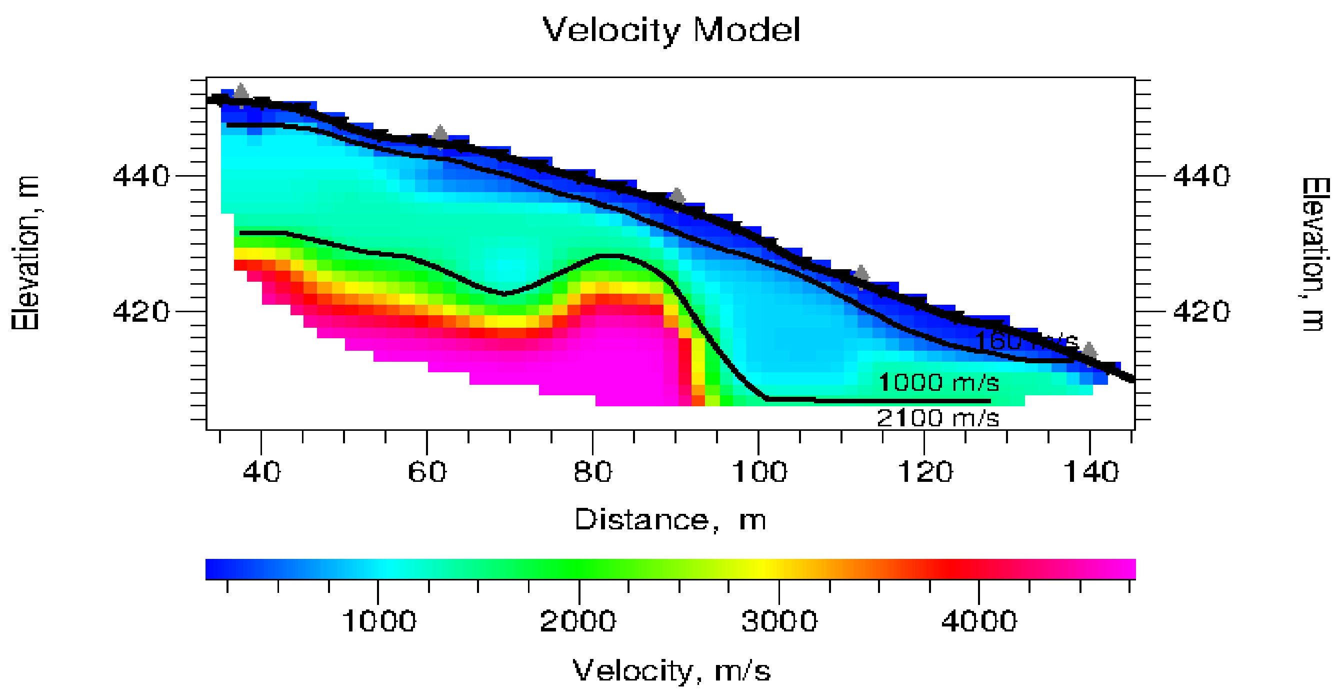
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the left of the profile.

CHAINAGE 37390 (T 11-P1 SIDE) ACROSS ERT- W



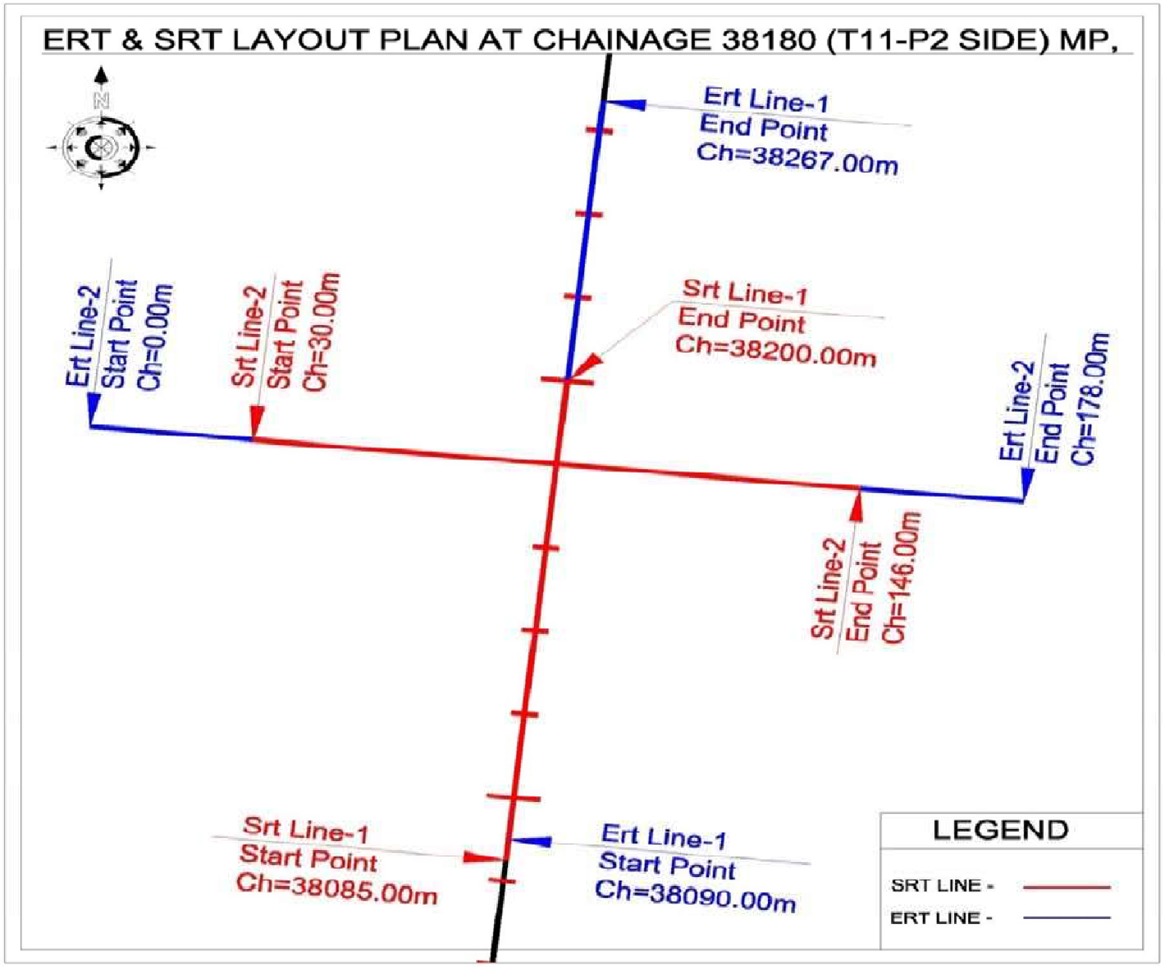
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the left of the profile.

CHAINAGE 37390 (T 11-P1 SIDE) ACROSS SRT

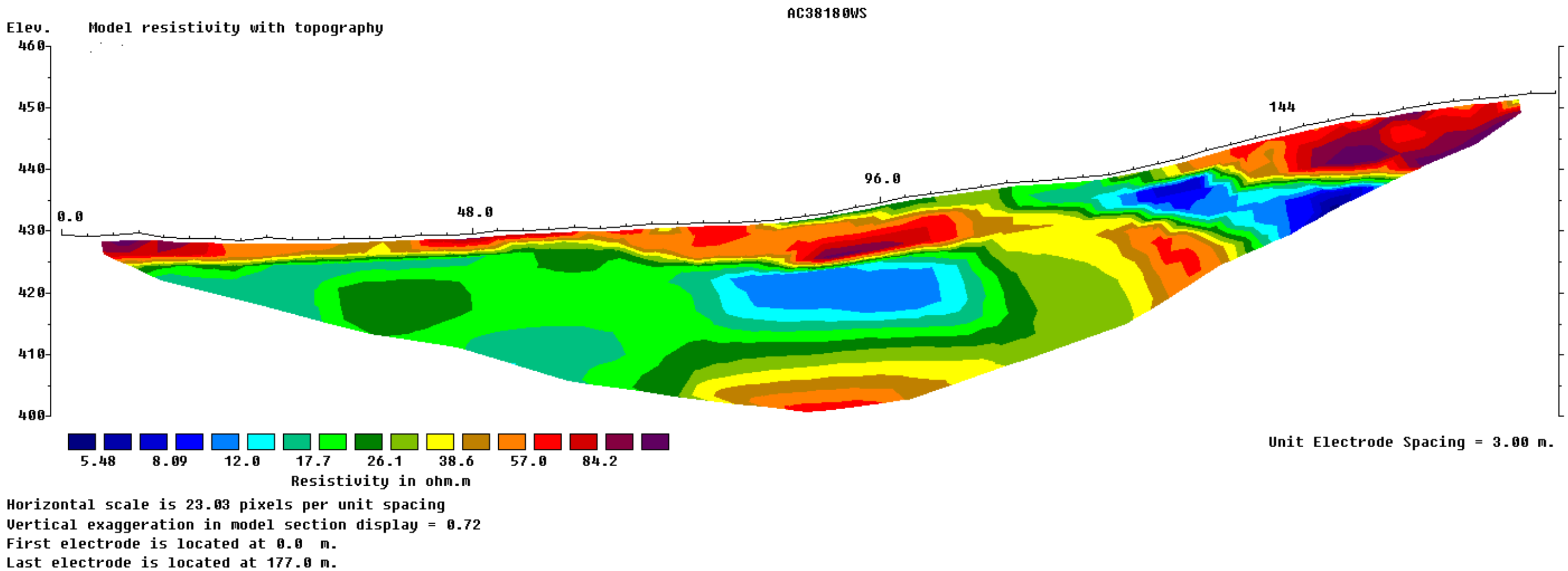


SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 1000m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 2100m/s and is likely to correspond to highly weathered rock.

ERT & SRT LAYOUT PLAN AT CHAINAGE 38180 (T 11-P2 SIDE)

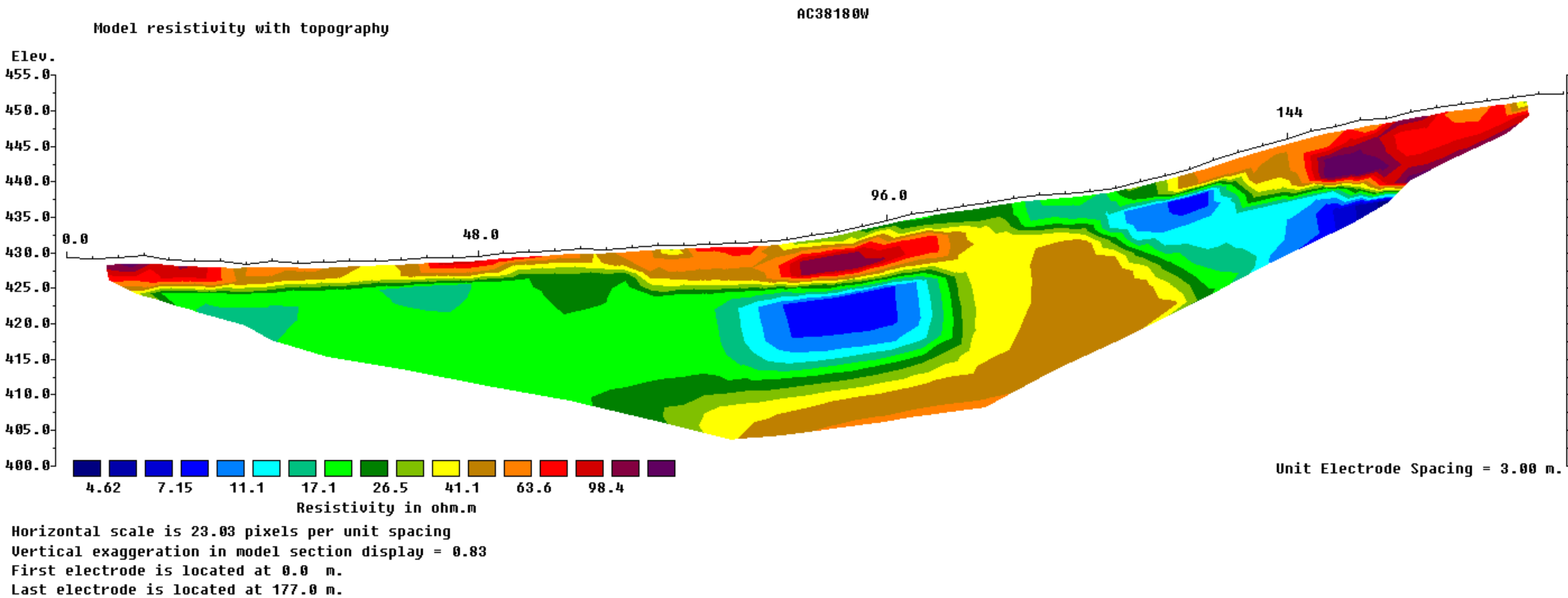


CHAINAGE 38180 (T 11-P2 SIDE)ACROSS ERT- WS



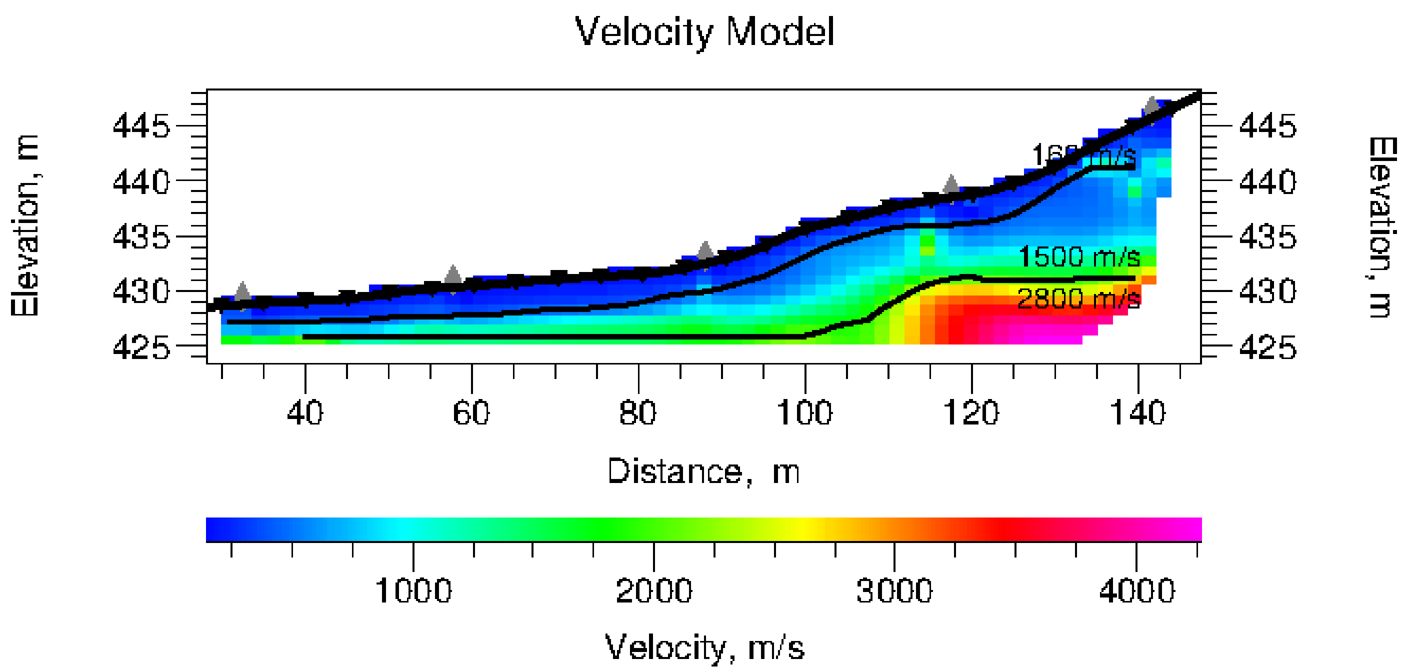
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the center and right of the profile.

CHAINAGE 38180 (T 11-P2 SIDE) ACROSS ERT W



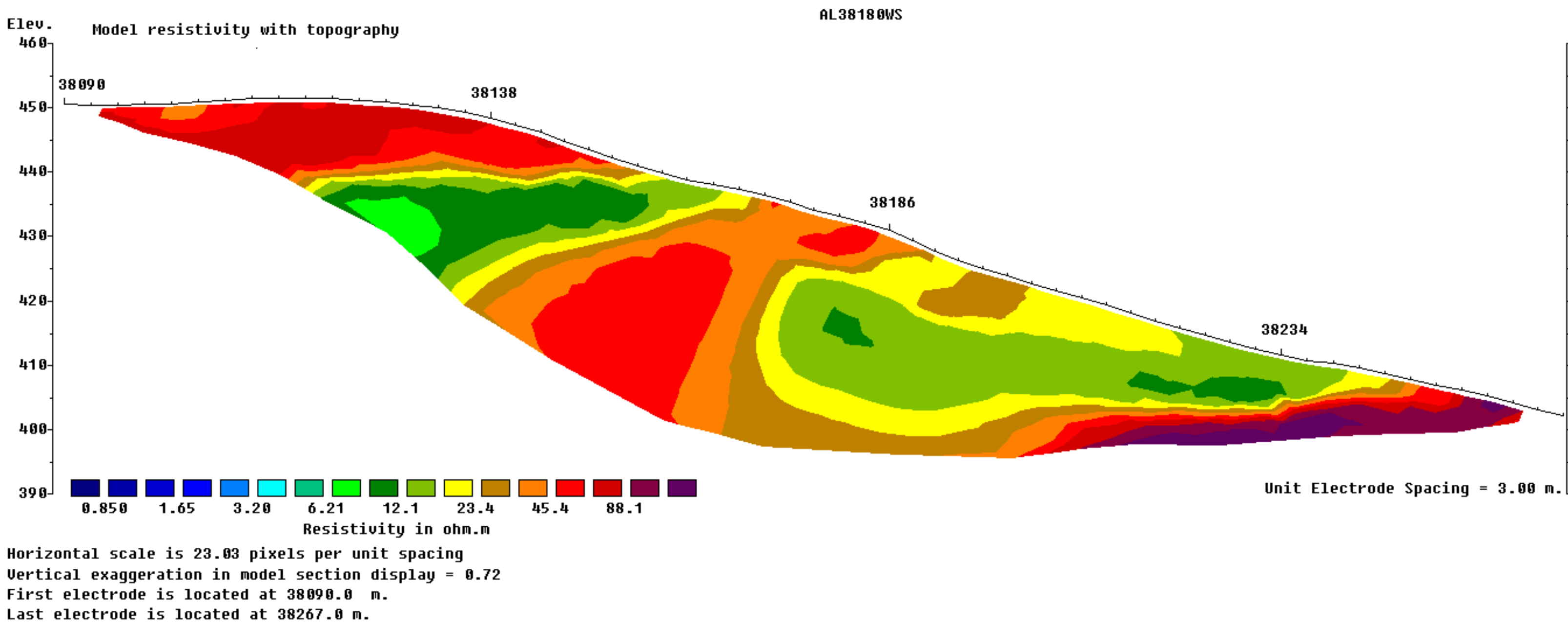
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the center and right of the profile.

CHAINAGE 38180 (T 11-P2 SIDE) ACROSS SRT



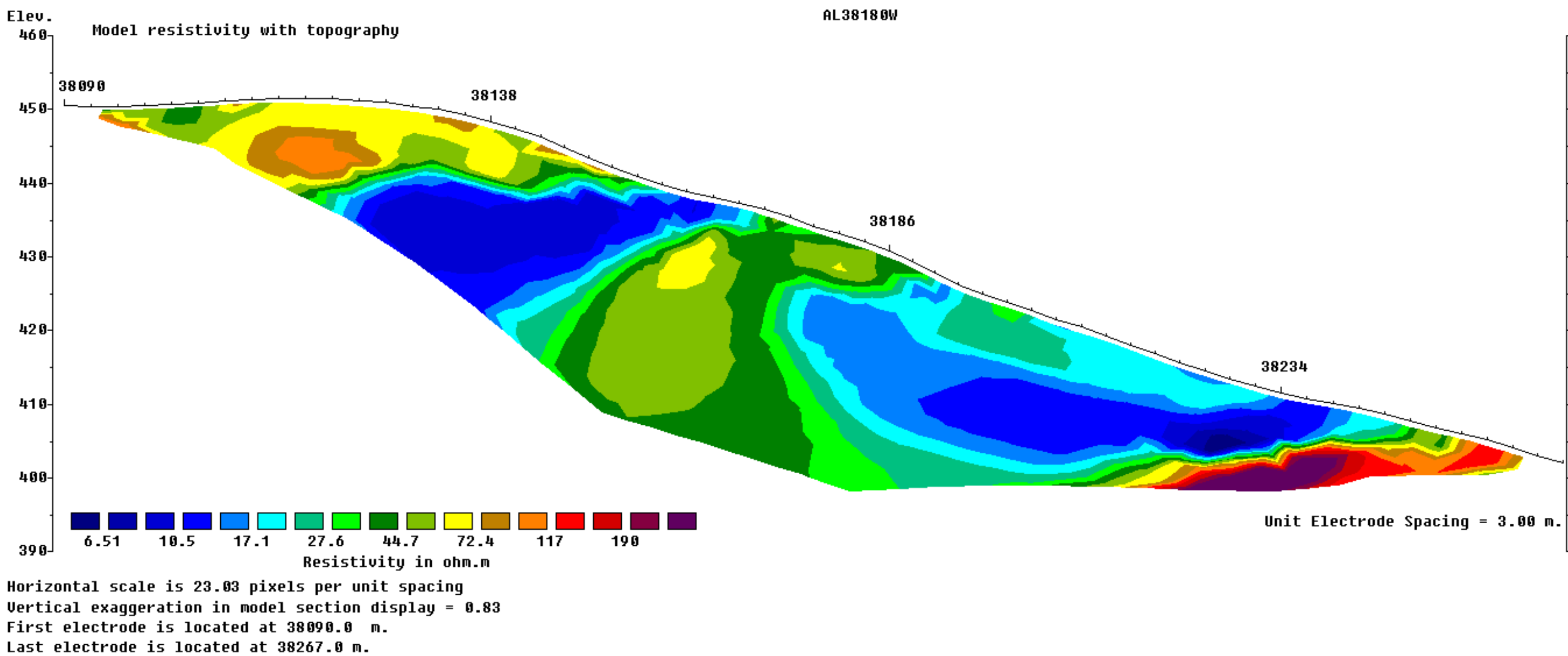
SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 1500m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 2800m/s and is likely to correspond to highly weathered rock.

CHAINAGE 38180 (T 11-P2 SIDE) ALONG ERT WS



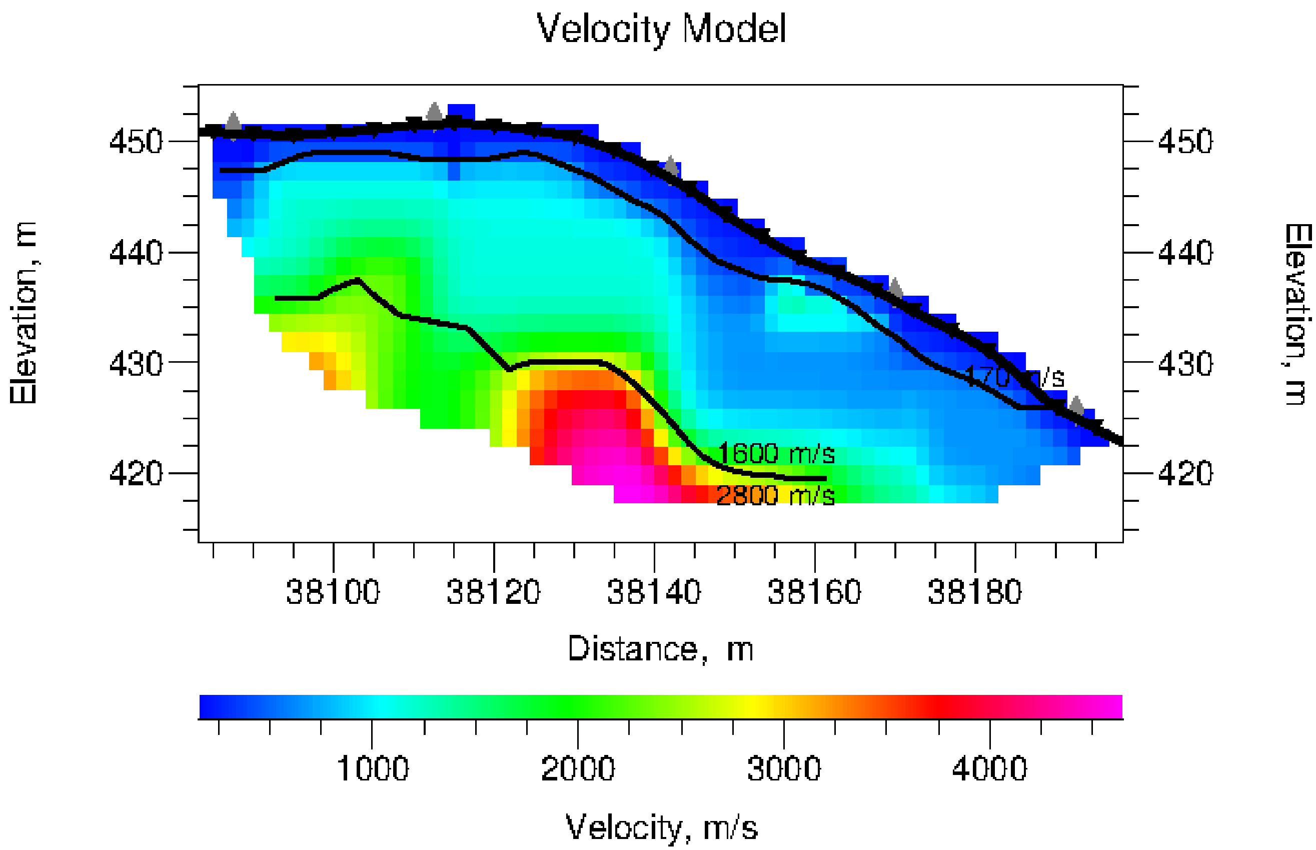
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the left and right of the profile.

CHAINAGE 38180 (T 11-P2 SIDE) ALONG ERT W



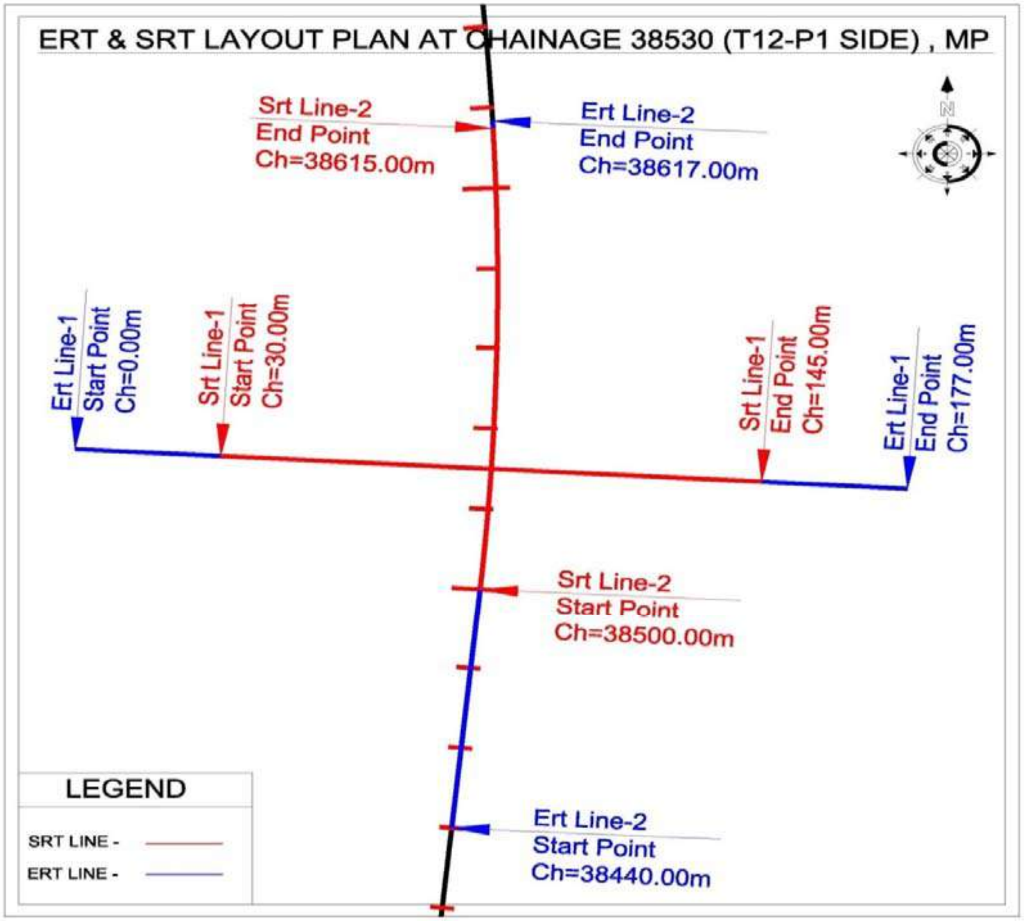
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the left and right of the profile.

CHAINAGE 38180 (T 11-P2 SIDE) ALONG SRT

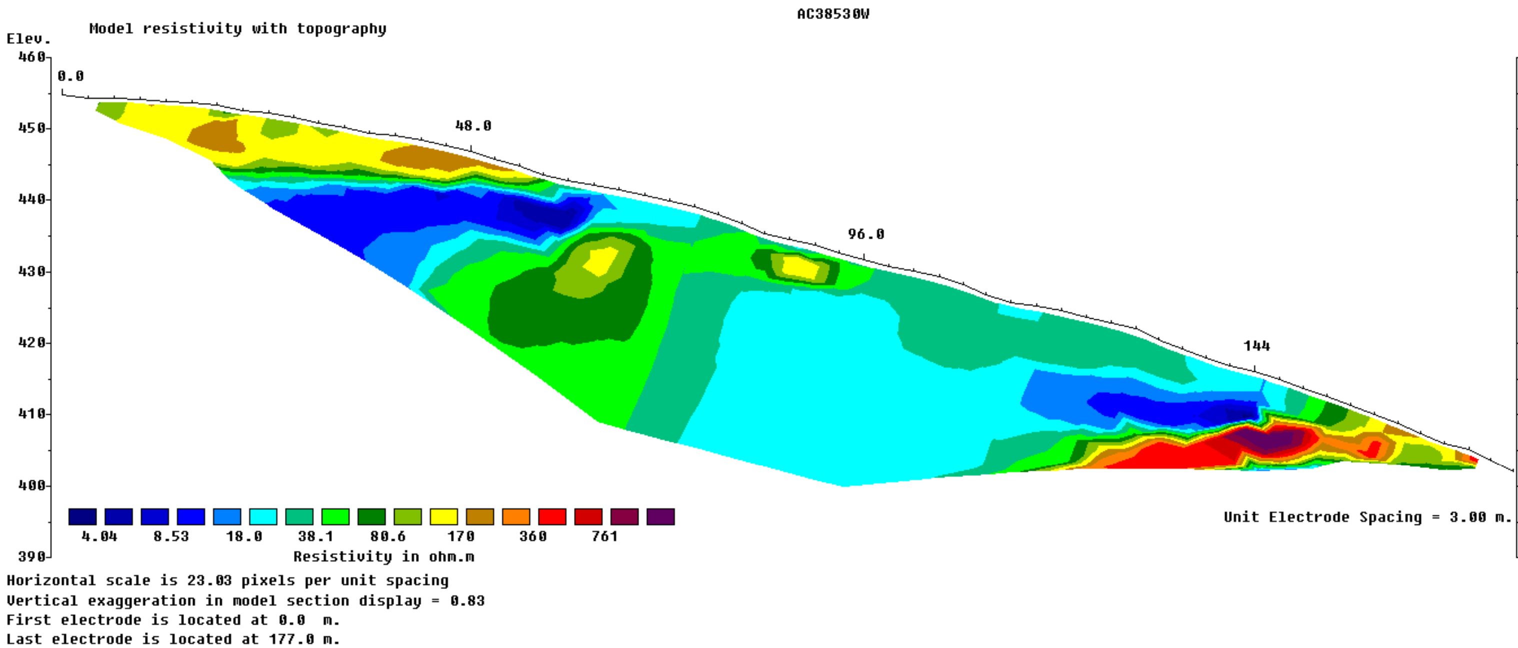


SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 1600m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 2800m/s and is likely to correspond to highly weathered rock.

ERT & SRT LAYOUT PLAN AT CHAINAGE 38530 (T 12-P1 SIDE)

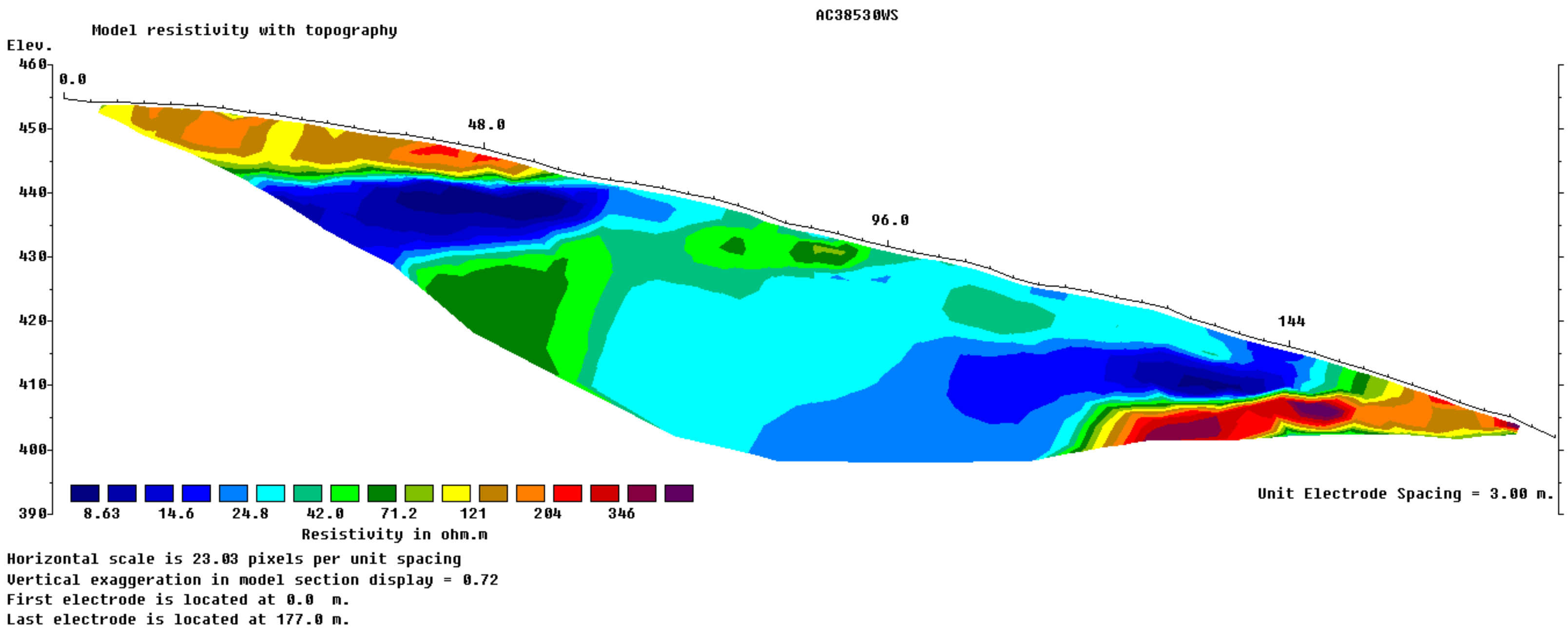


CHAINAGE 38530 (T 12-P1 SIDE) ACROSS ERT- W



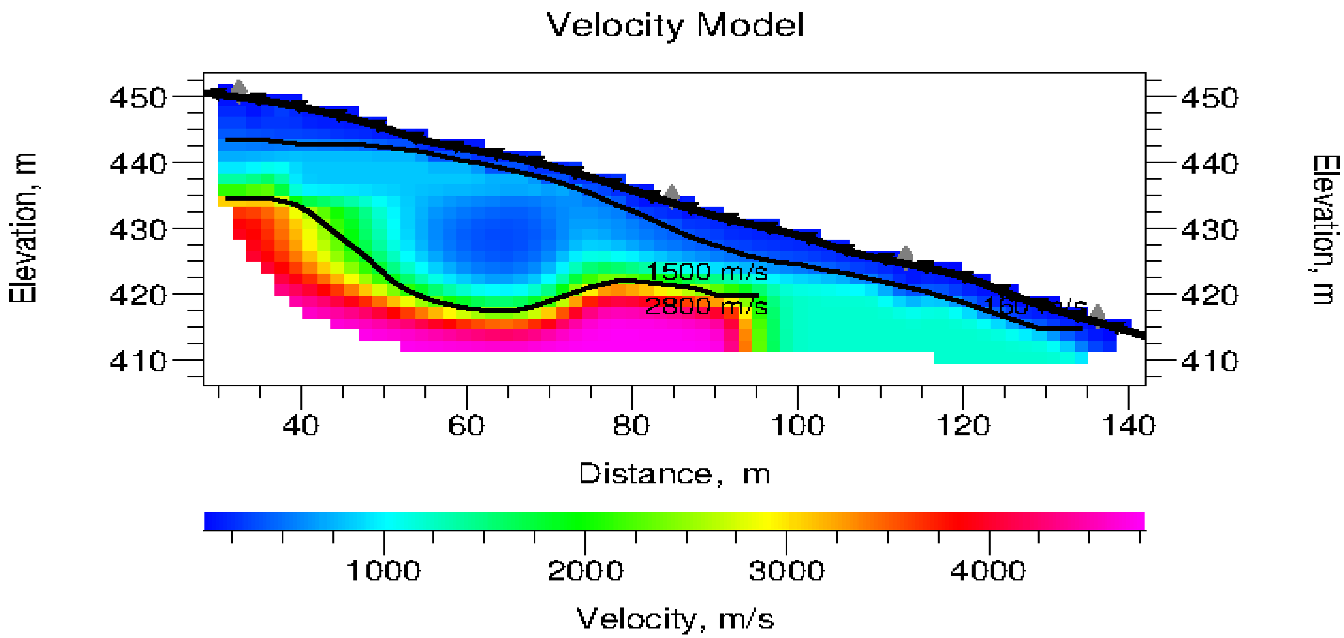
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the left and right of the profile.

CHAINAGE 38530 (T 12-P1 SIDE) ACROSS ERT- WS



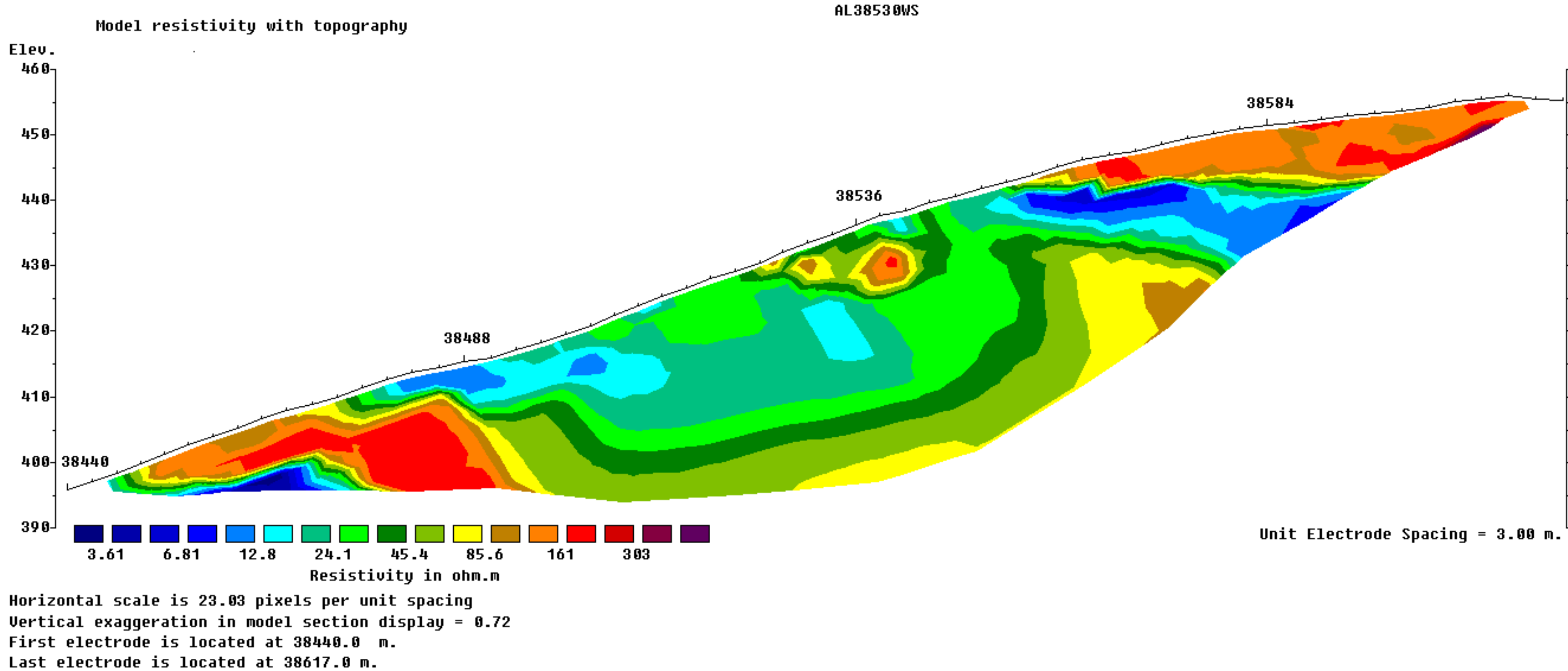
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the left and right of the profile.

CHAINAGE 38530 (T 12-P1 SIDE) ACROSS SRT



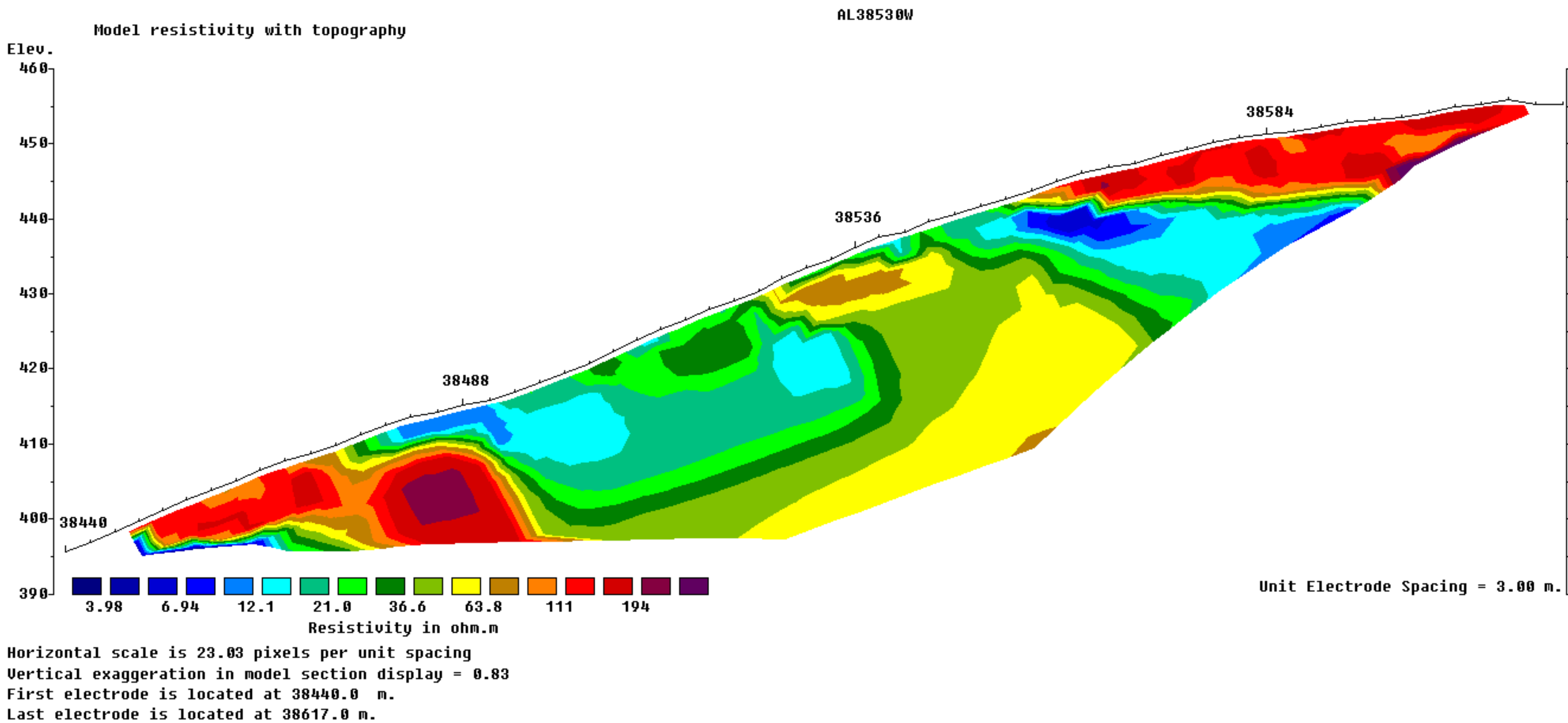
SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 1500m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 2800m/s and is likely to correspond to highly weathered rock.

CHAINAGE 38530 (T 12-P1 SIDE) ALONG ERT- WS



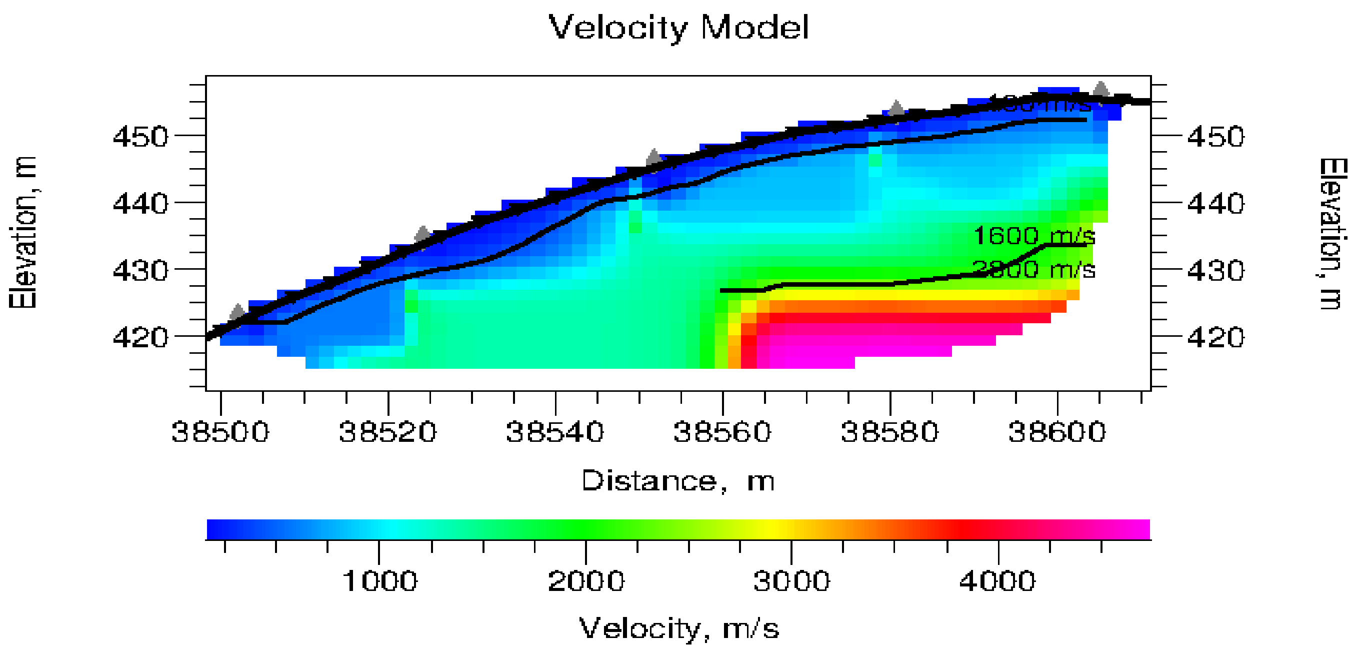
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the center and right of the profile.

CHAINAGE 38530 (T 12-P1 SIDE) ALONG ERT- W



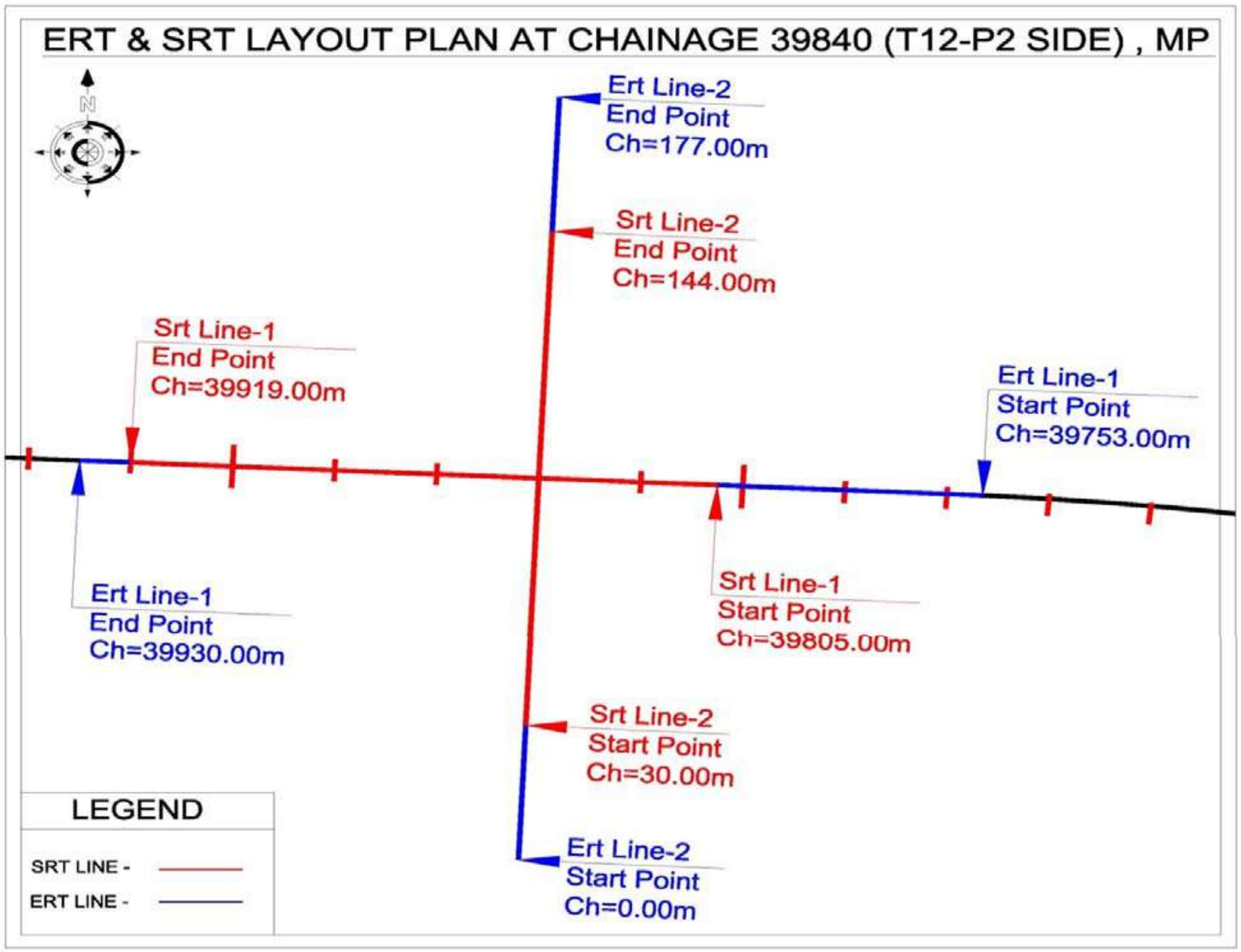
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the center and right of the profile.

CHAINAGE 38530 (T 12-P1 SIDE) ALONG SRT

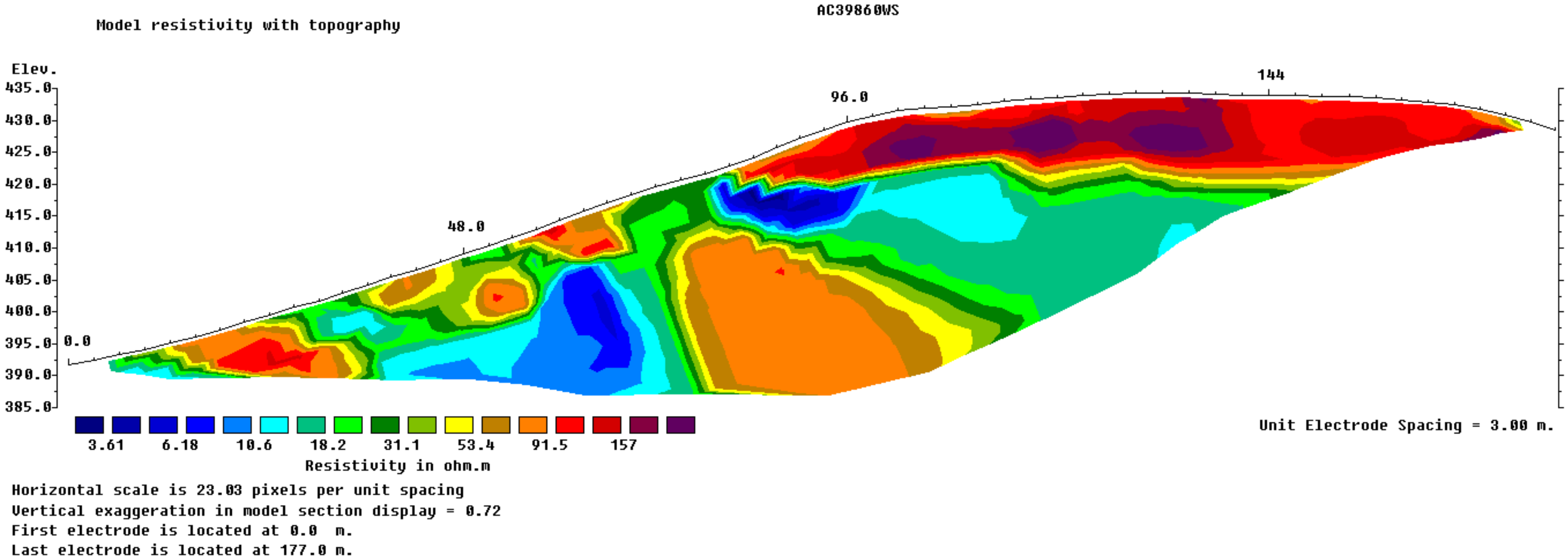


SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 1600m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 2800m/s and is likely to correspond to highly weathered rock.

ERT & SRT LAYOUT PLAN AT CHAINAGE 39840 (T 12-P2 SIDE)

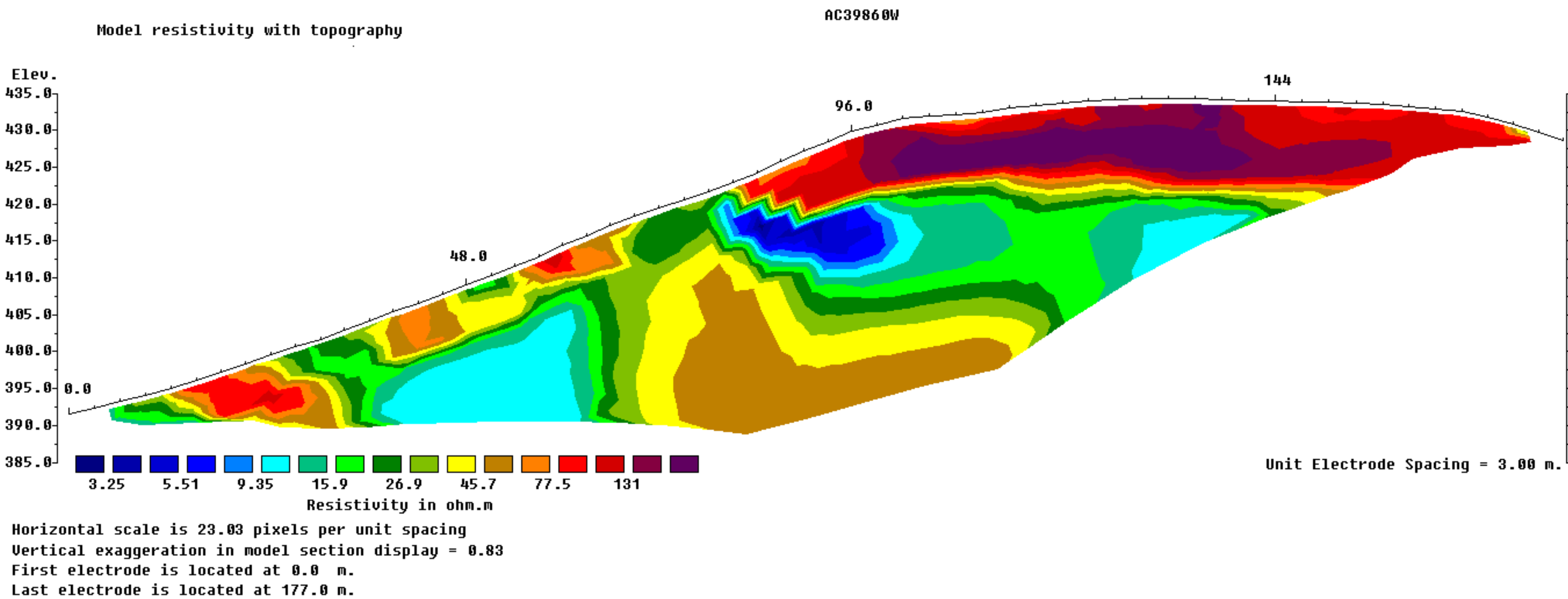


CHAINAGE 39840 (T 12-P2 SIDE) ACROSS ERT -WS



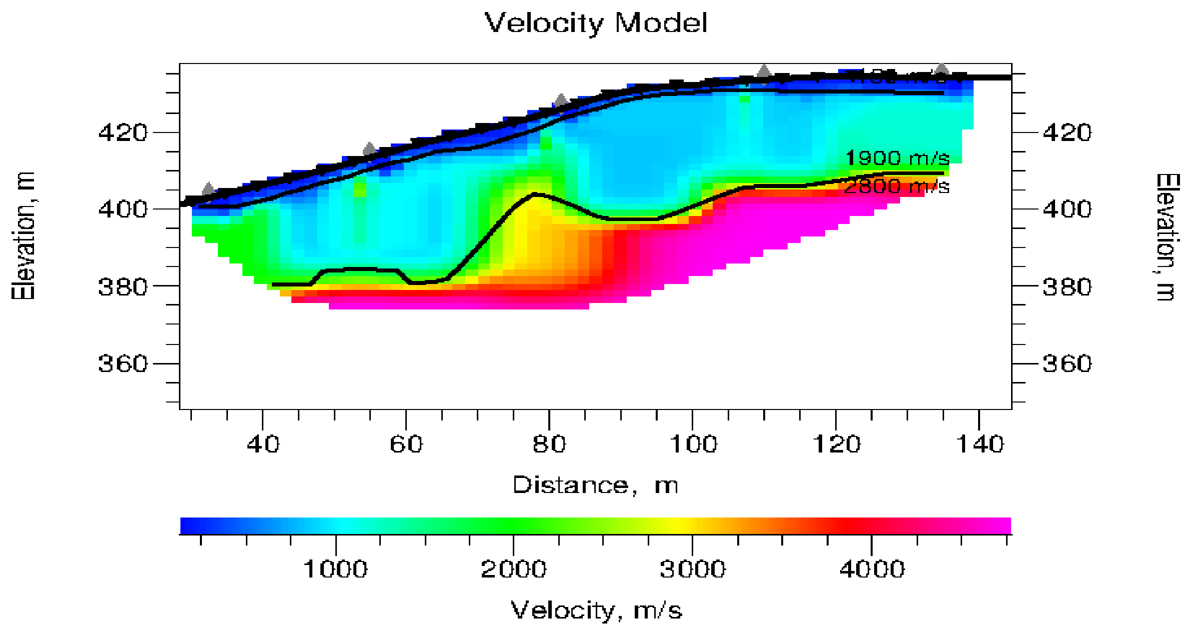
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the left and right of the profile.

CHAINAGE 39840 (T 12-P2 SIDE) ACROSS ERT W



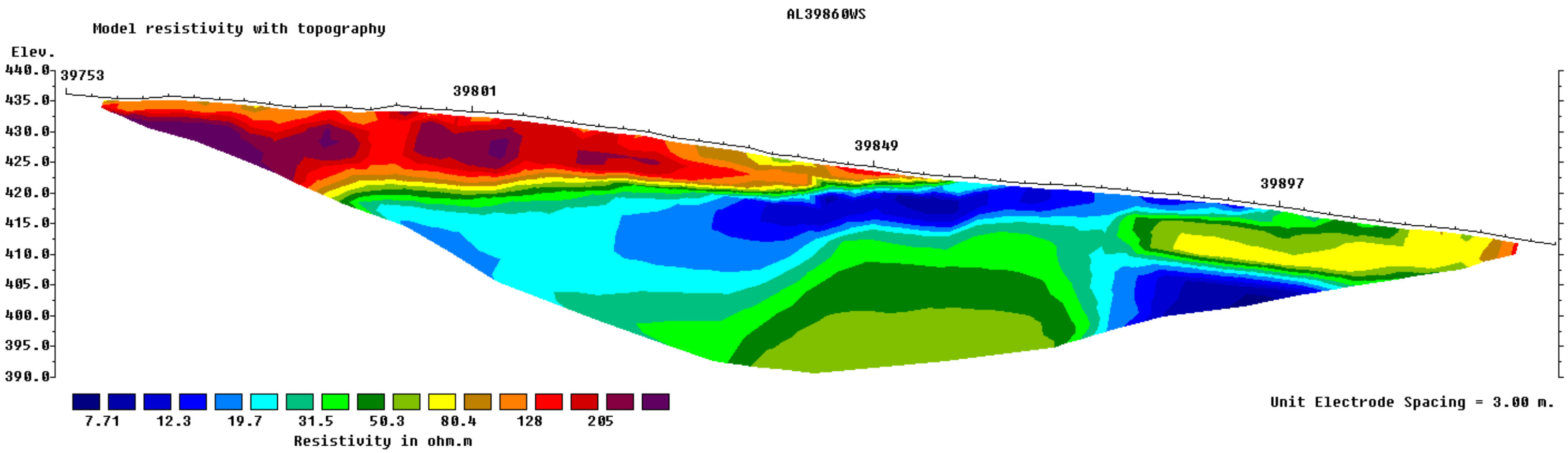
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the left and right of the profile.

CHAINAGE 39840 (T 12-P2 SIDE) ACROSS SRT



SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 1900m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 2800m/s and is likely to correspond to highly weathered rock.

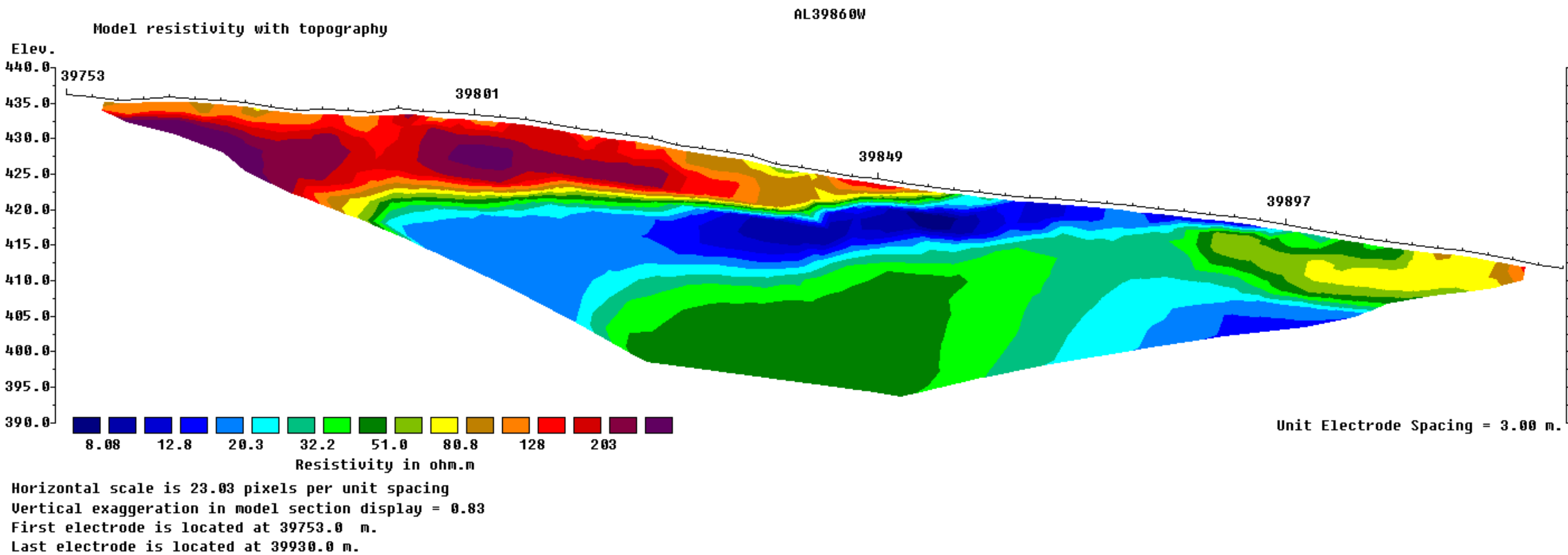
CHAINAGE 39840 (T 12-P2 SIDE) ALONG ERT -WS



Horizontal scale is 23.03 pixels per unit spacing
Vertical exaggeration in model section display = 0.72
First electrode is located at 39753.0 m.
Last electrode is located at 39930.0 m.

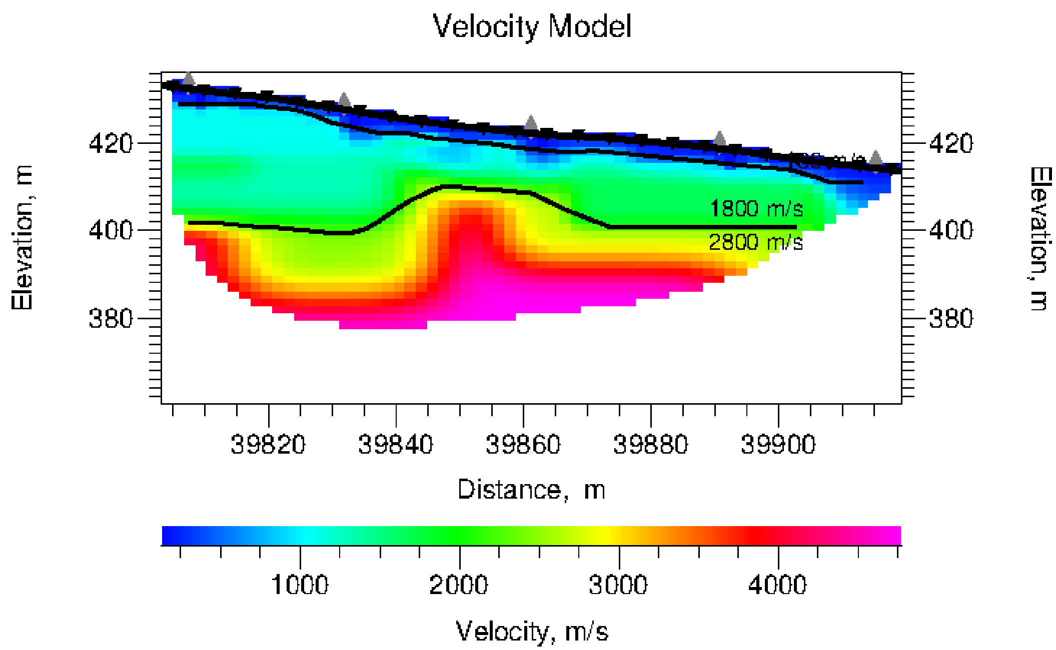
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the left-center and right of the profile.

CHAINAGE 39840 (T 12-P2 SIDE) ALONG ERT W



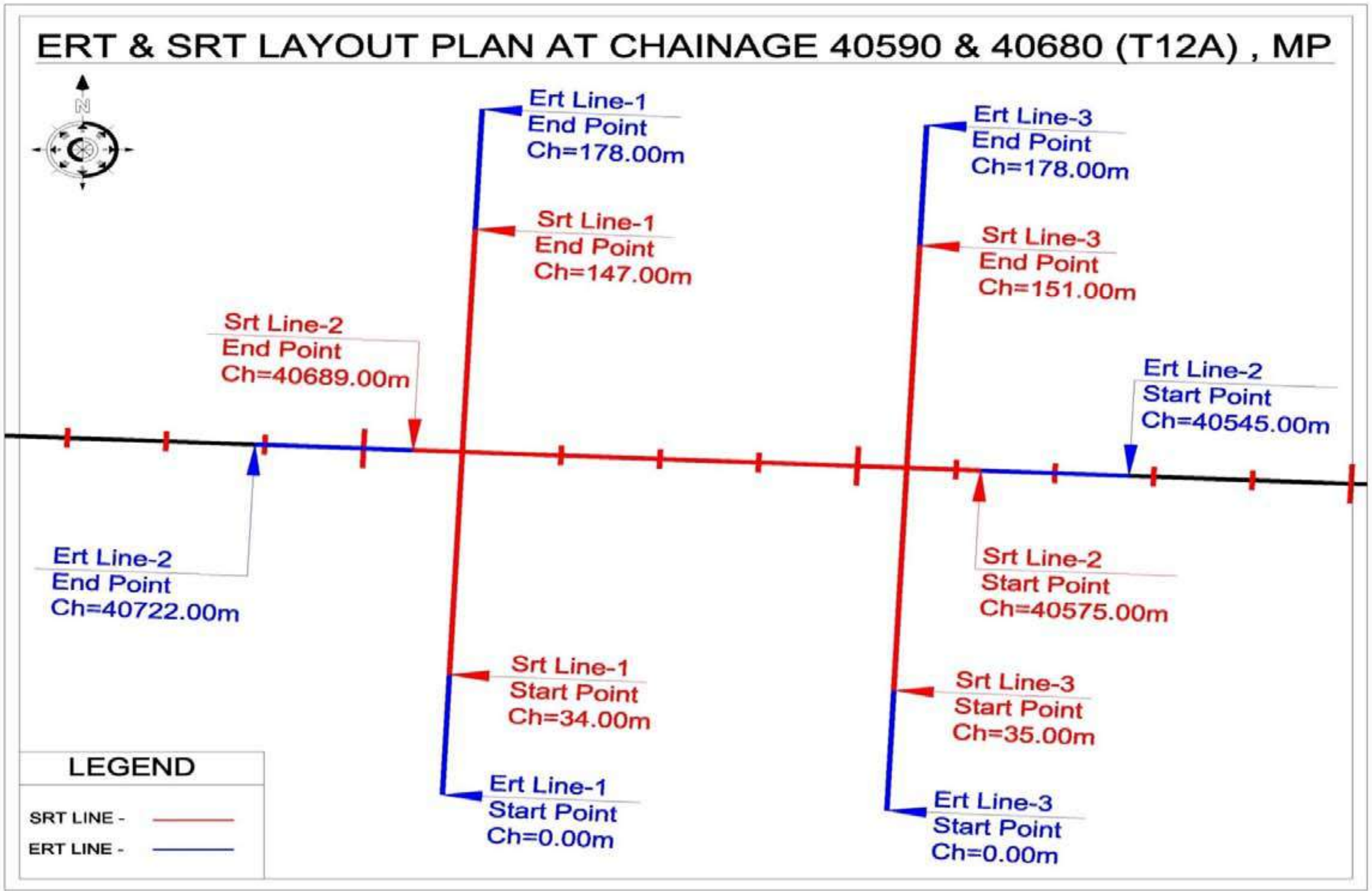
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the left-center and right of the profile.

CHAINAGE 39840 (T 12-P2 SIDE) ALONGSRT

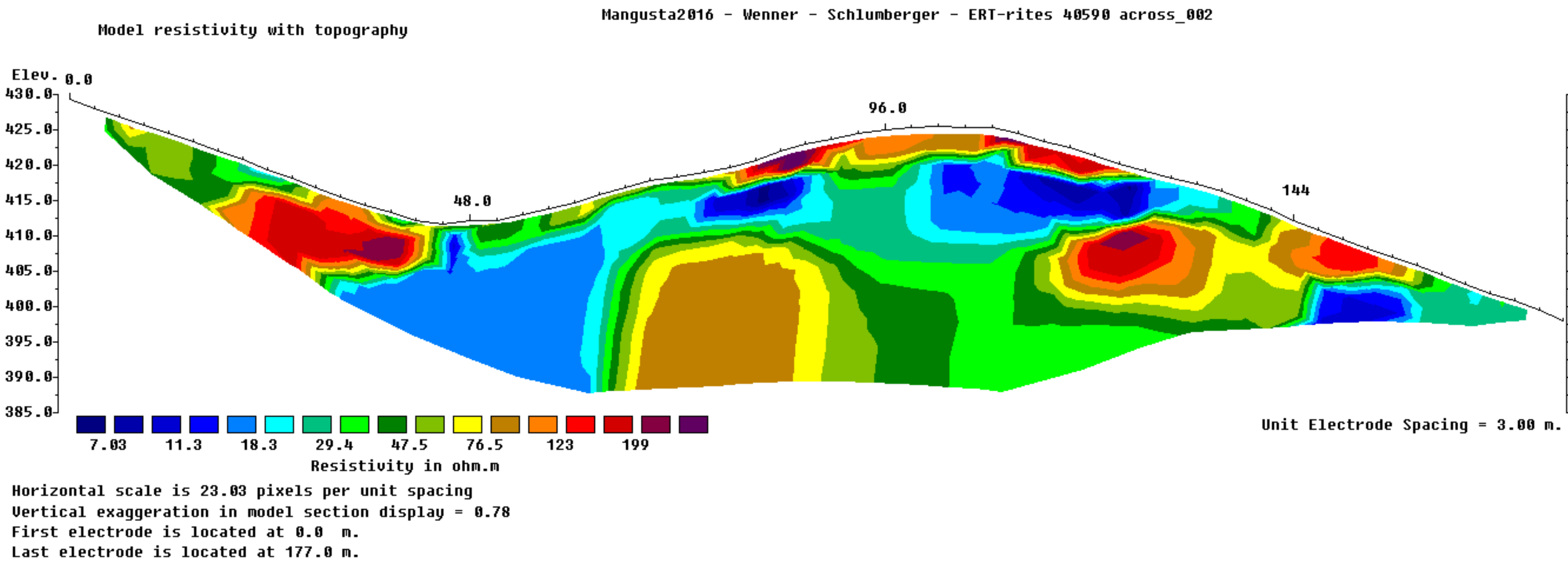


SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 1800m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 2800m/s and is likely to correspond to highly weathered rock.

ERT & SRT LAYOUT PLAN AT CHAINAGE 40590 & 40680 (T12A)

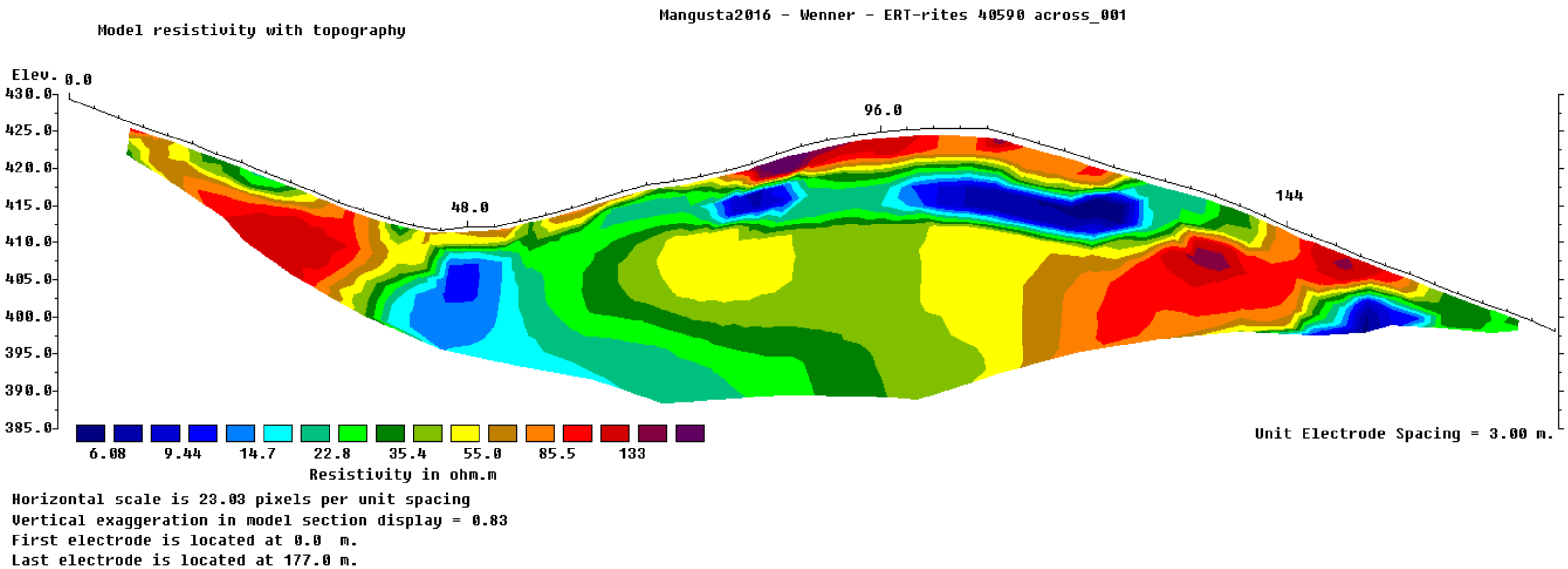


CHAINAGE 40590 ACROSS ERT -WS



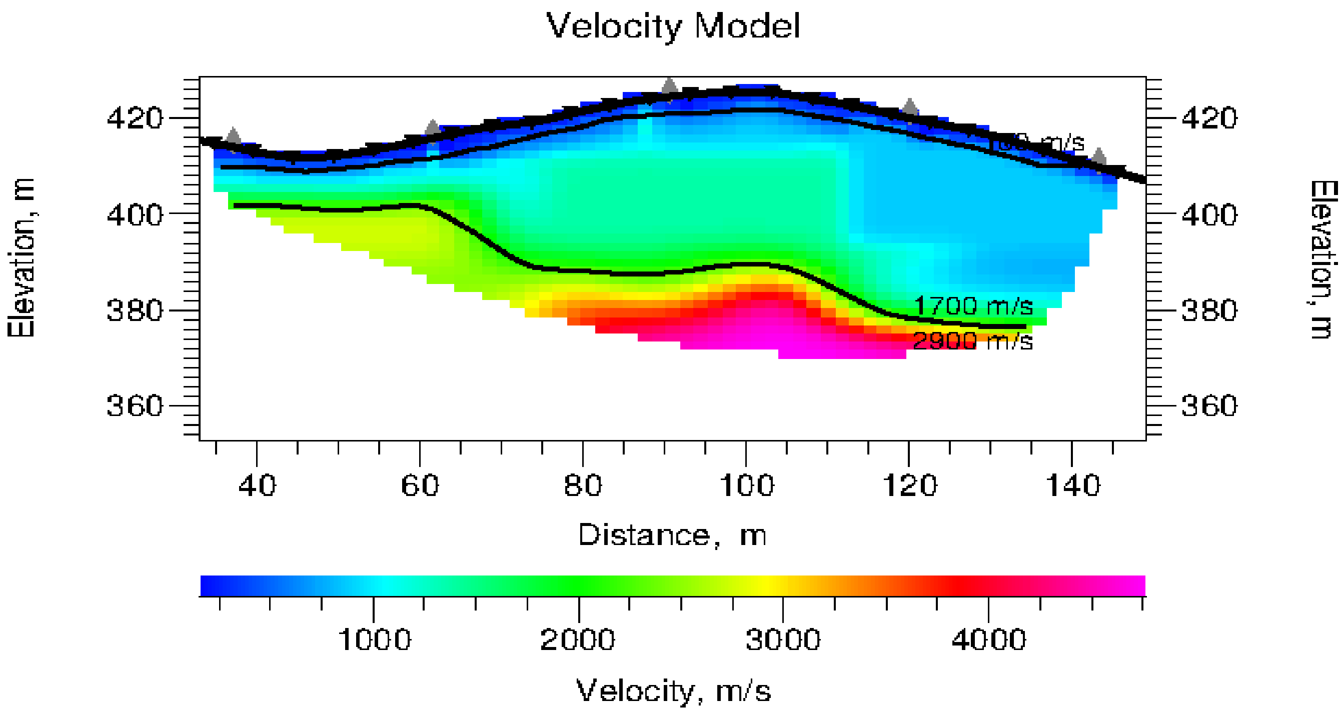
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the left of the profile. Shallow low resistivity zones are present in remaining part of profile.

CHAINAGE 40590 ACROSS ERT -W



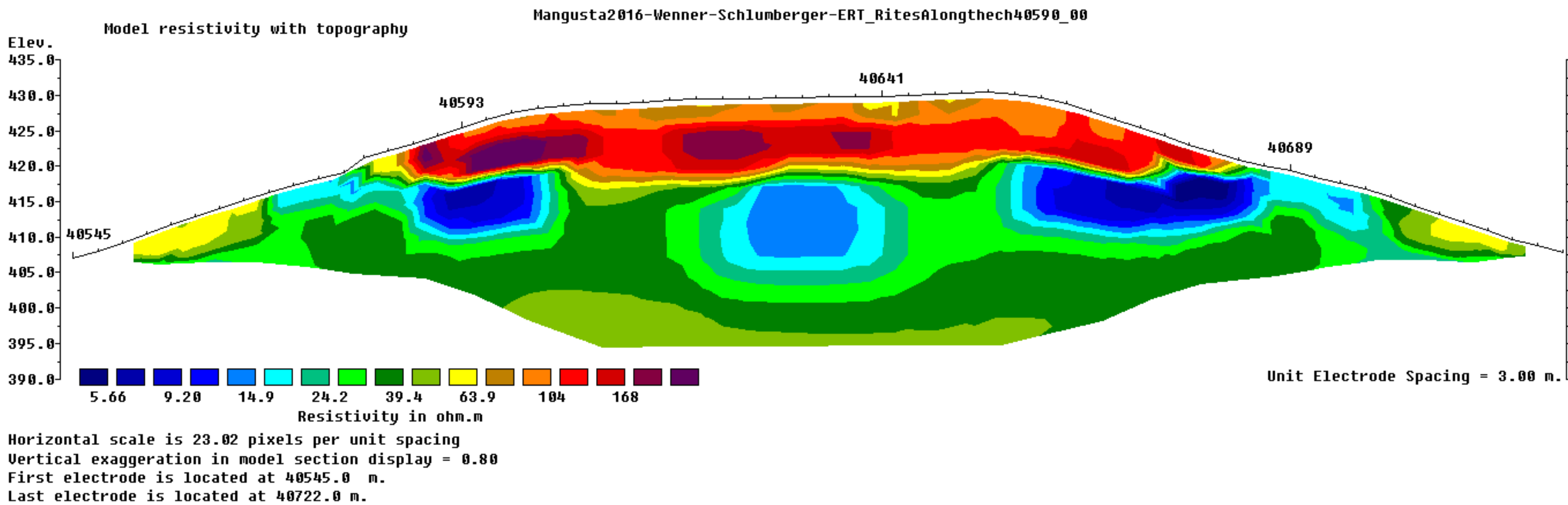
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the left of the profile. Shallow low resistivity zones are present in remaining part of profile.

CHAINAGE 40590 ACROSS SRT



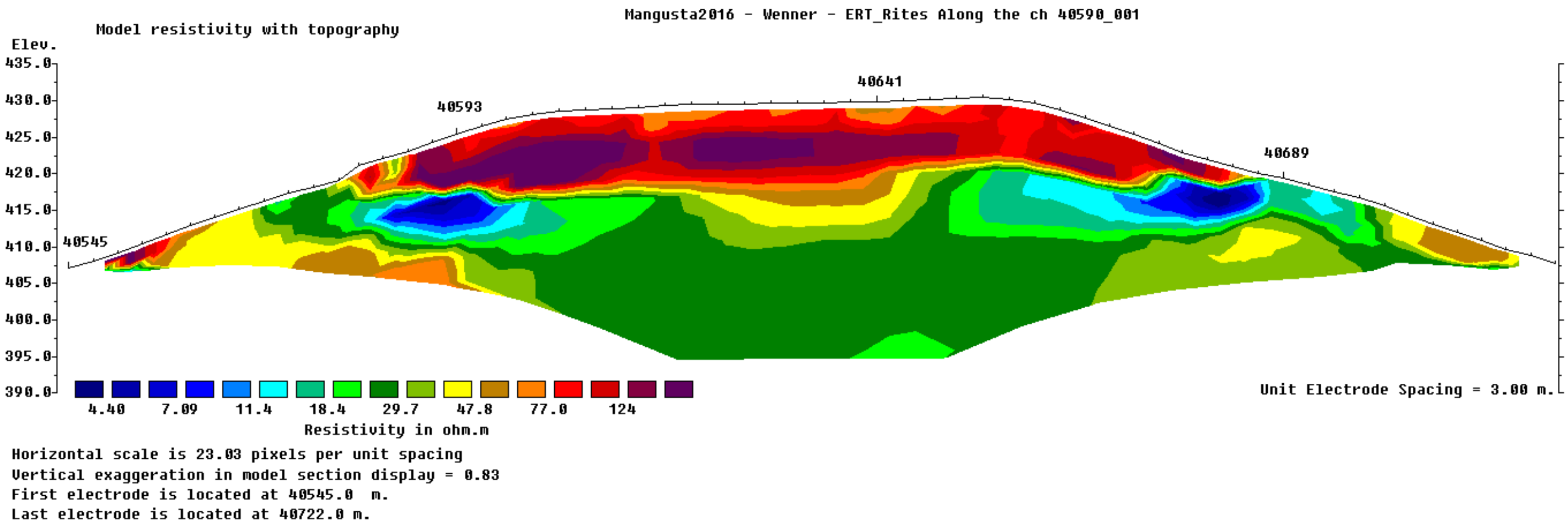
SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 1700m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 2900m/s and is likely to correspond to highly weathered rock.

CHAINAGE 40590 ALONG ERT -WS



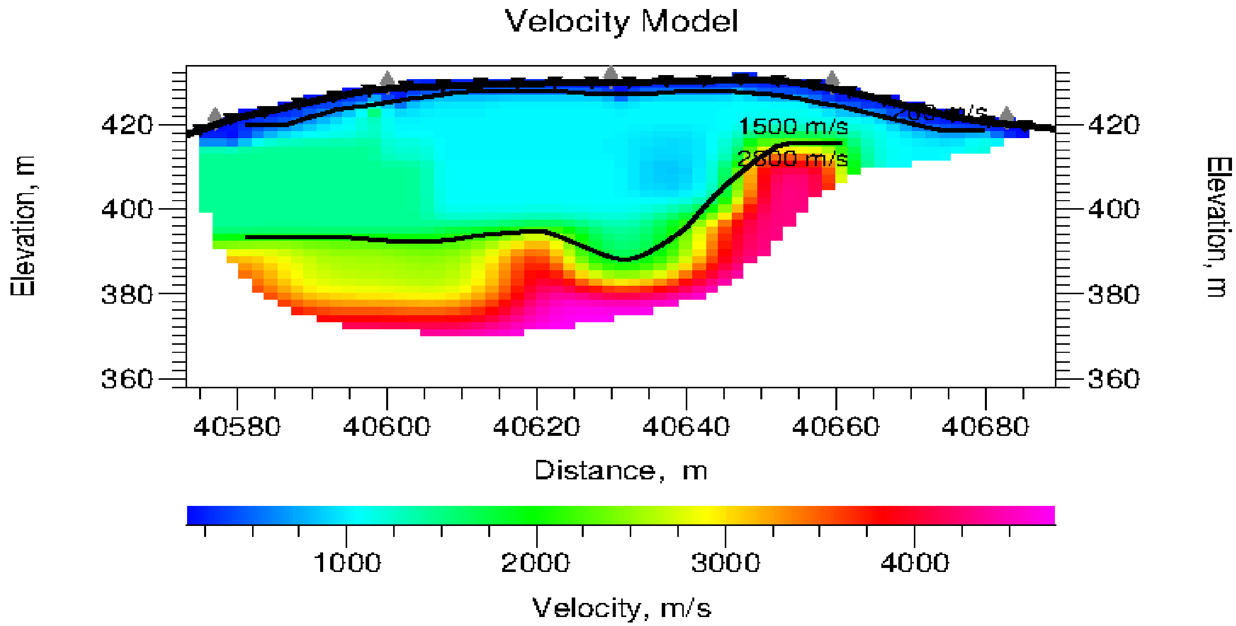
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows primarily vertical changes in resistivity values and lower values in the middle section of the profile, after a high resistivity top.

CHAINAGE 40590 ALONG ERT -W



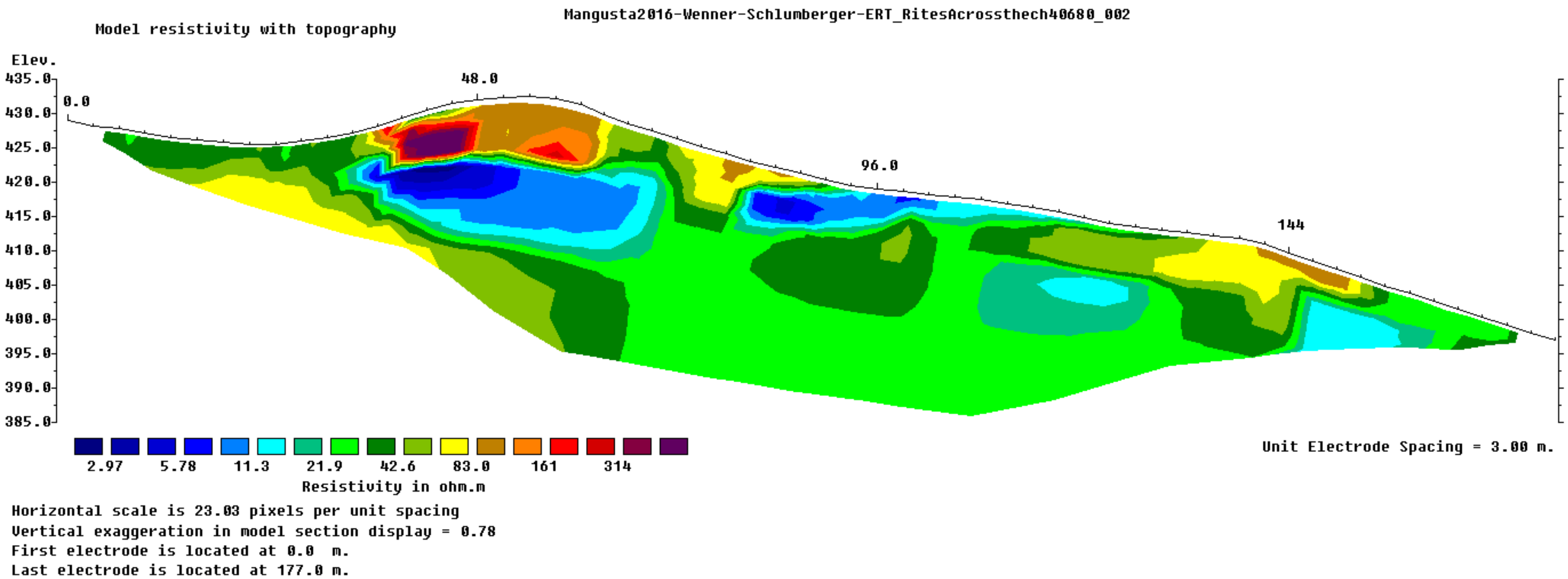
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows primarily vertical changes in resistivity values and lower values in the middle section of the profile, after a high resistivity top.

CHAINAGE 40590 ACROSS SRT



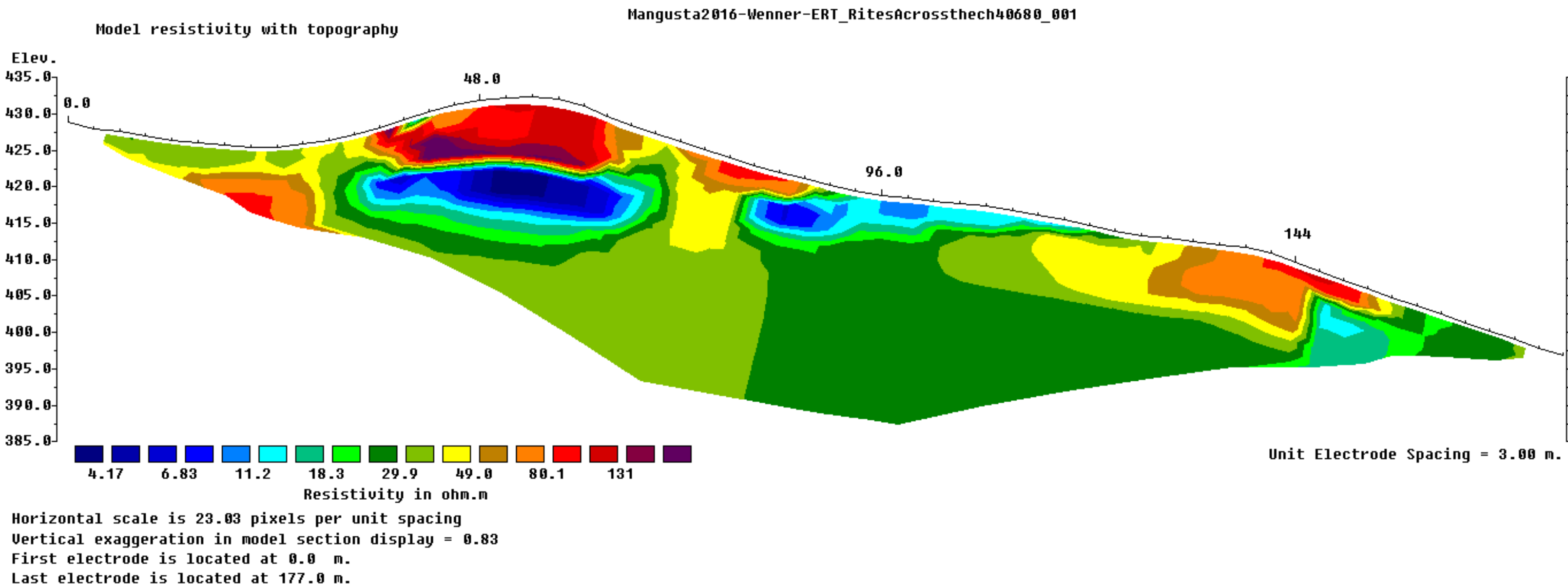
SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 1500m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 2800m/s and is likely to correspond to highly weathered rock.

CHAINAGE 40680 ACROSS ERT -WS



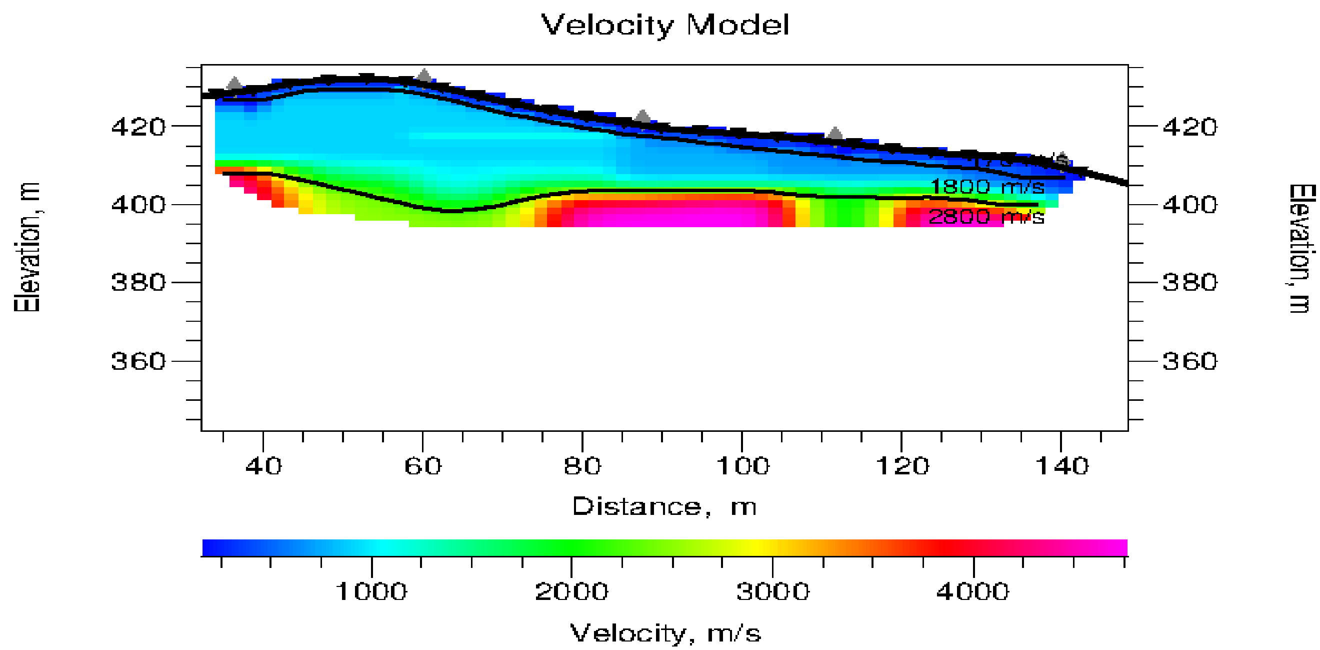
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows low resistivity values in entire profile.

CHAINAGE 40680 ACROSS ERT -W



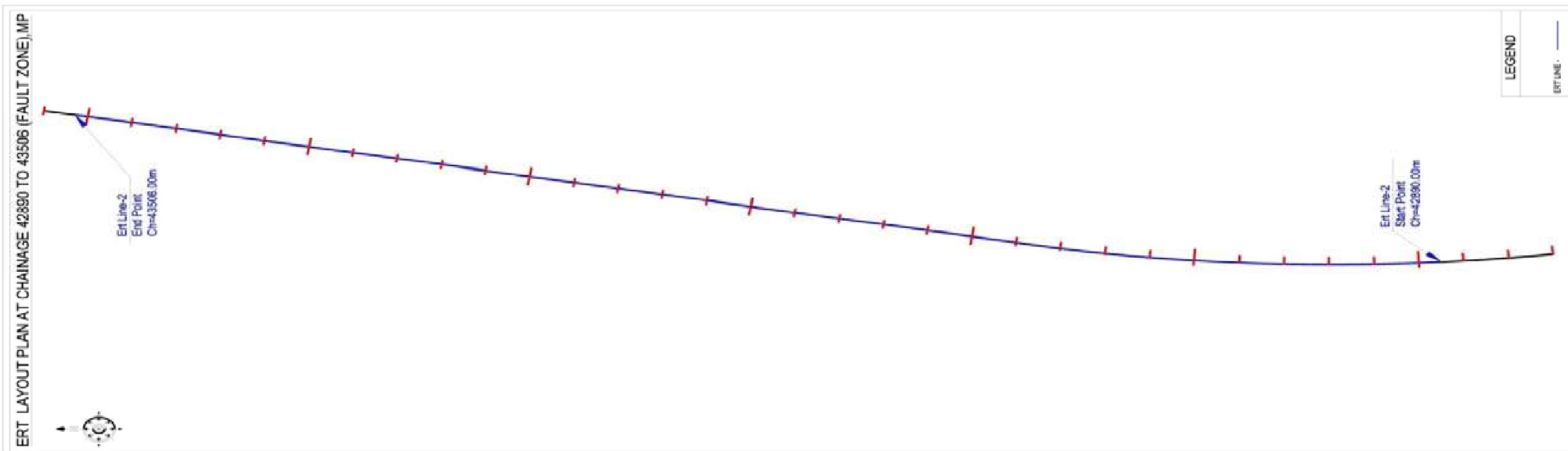
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows low resistivity values in entire profile.

CHAINAGE 40680 ACROSS

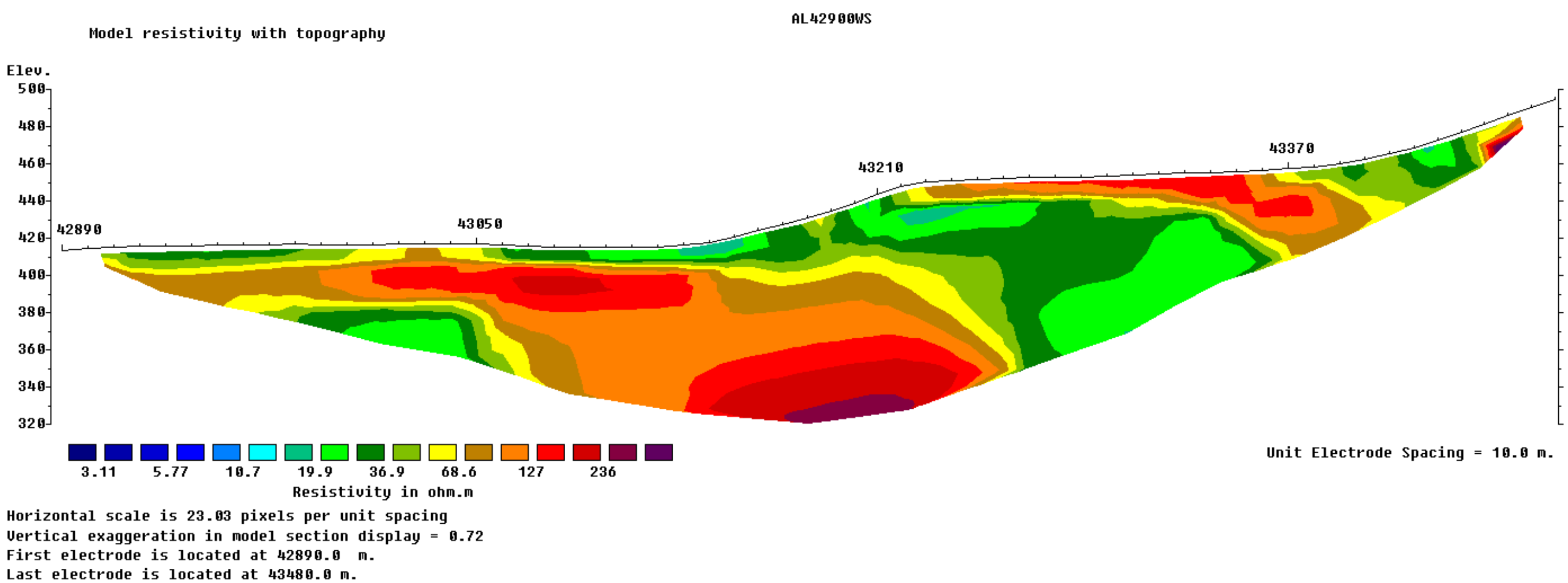


SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 1800m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 2800m/s and is likely to correspond to highly weathered rock.

ERT & SRT LAYOUT PLAN AT CHAINAGE 42890 TO 43506 (FAULT ZONE)

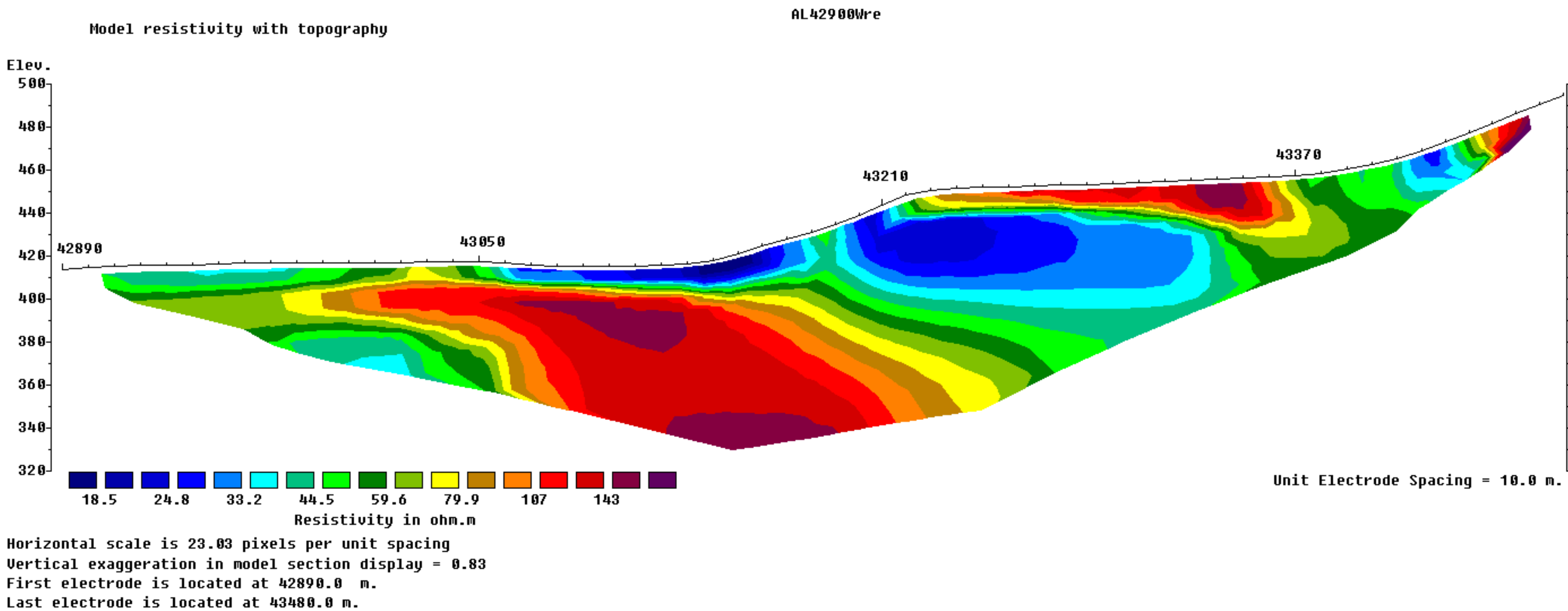


CHAINAGE 42890 TO 43506 (FAULT ZONE) ERT -WS



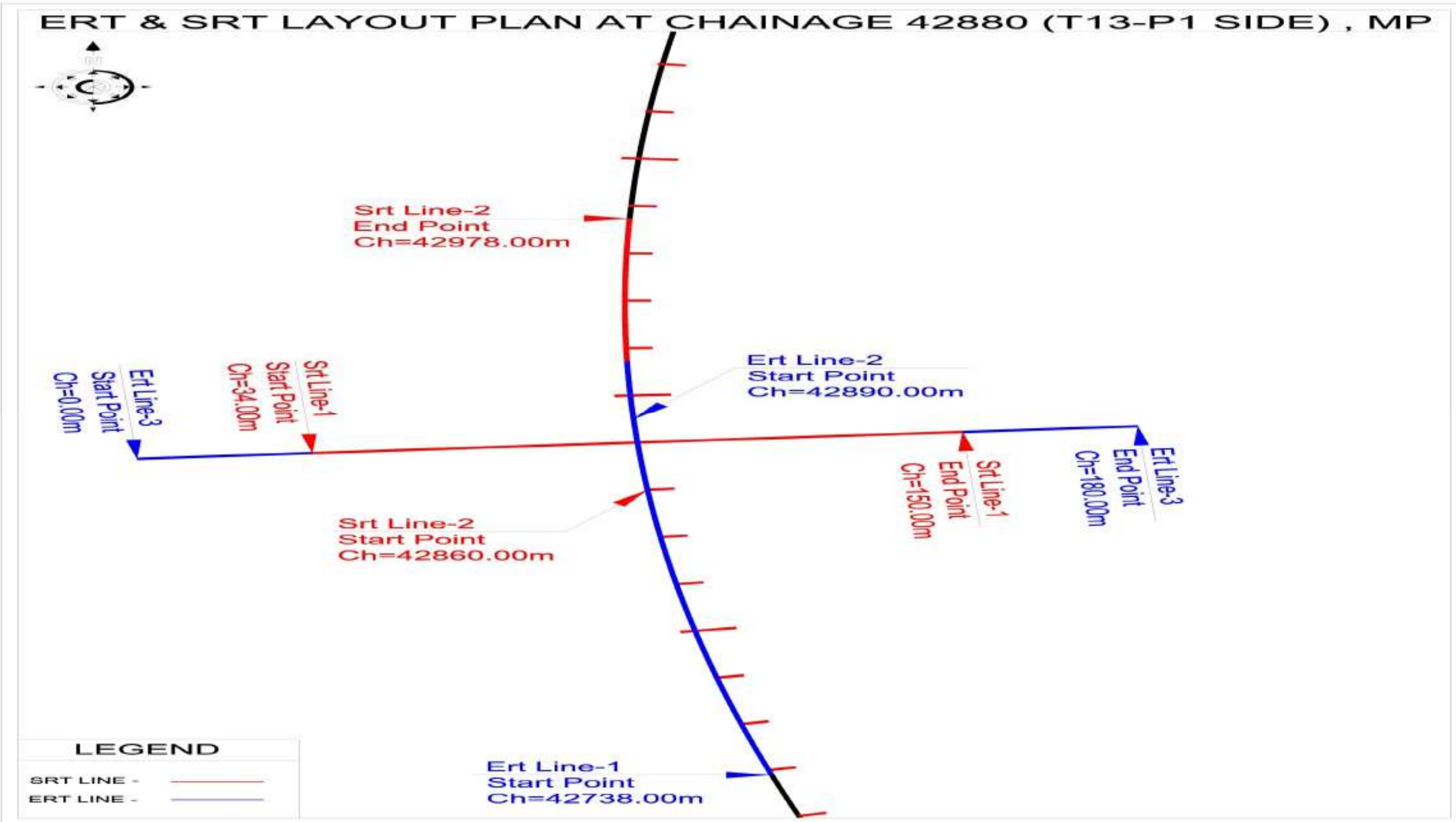
Interpretation: ERI profile length of 590m with electrode spacing of 10m, using a 60-electrode system was conducted. The profile shows presence of a low resistivity zone breaking the high resistivity zone towards right of the profile..

CHAINAGE 42890 TO 43506 (FAULT ZONE) ERT -W

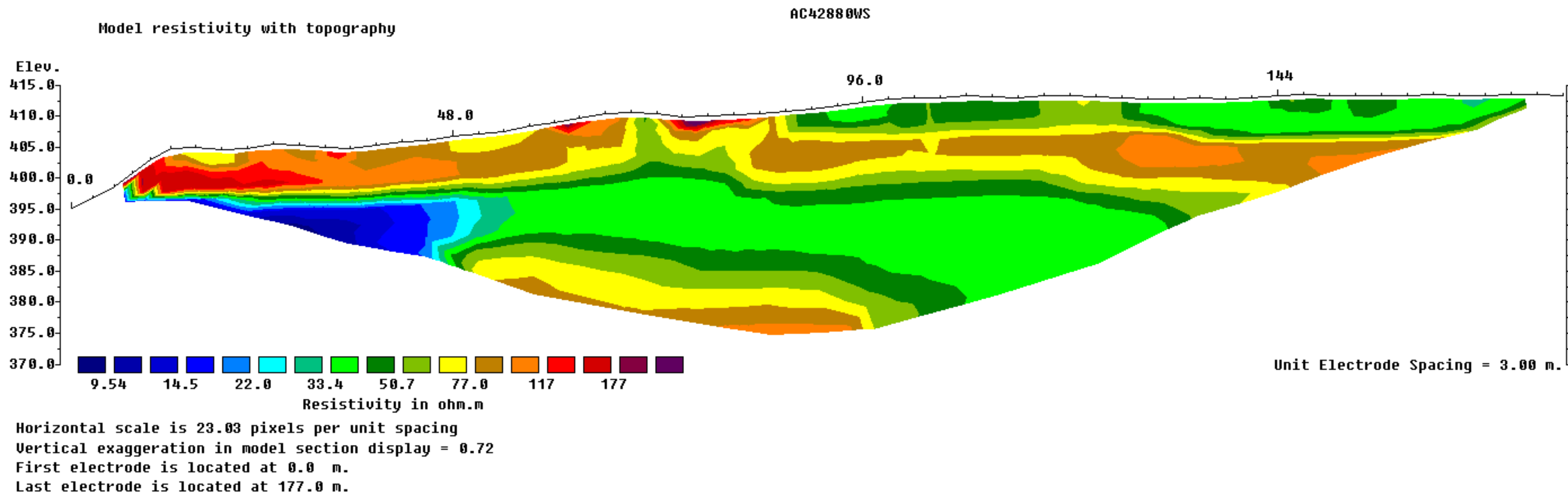


Interpretation: ERI profile length of 590m with electrode spacing of 10m, using a 60-electrode system was conducted. The profile shows presence of a low resistivity zone breaking the high resistivity zone towards right of the profile..

ERT & SRT LAYOUT PLAN AT CHAINAGE 42880 (T13-P1 SIDE)

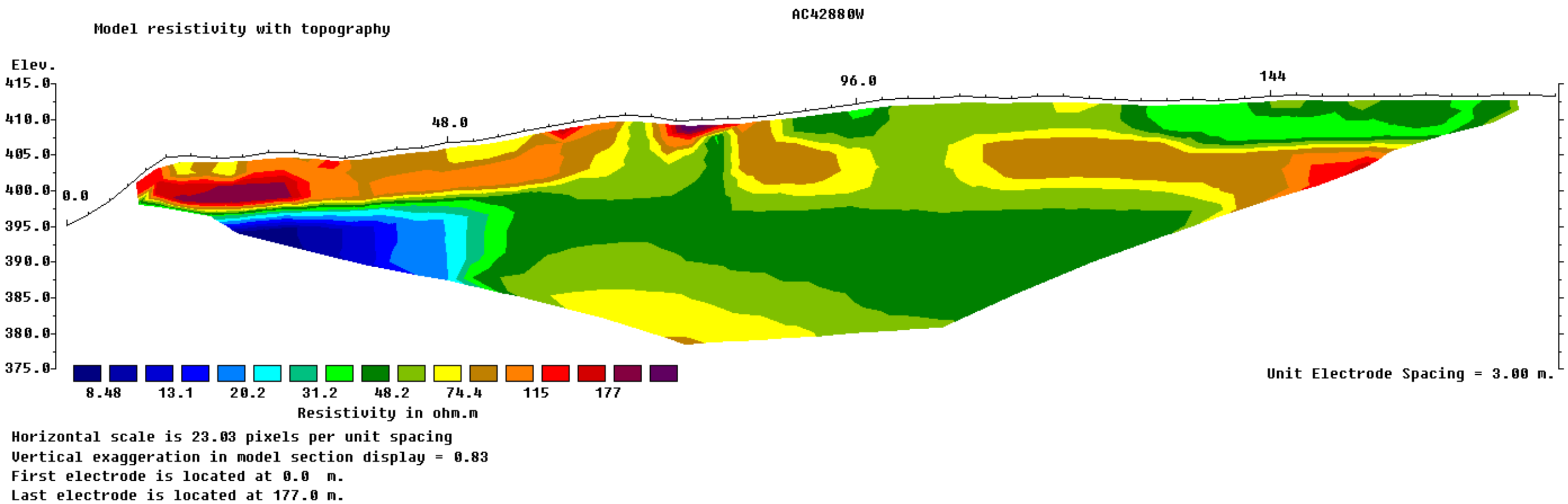


CHAINAGE 42880 (T13-P1 SIDE) ACROSS ERT -WS



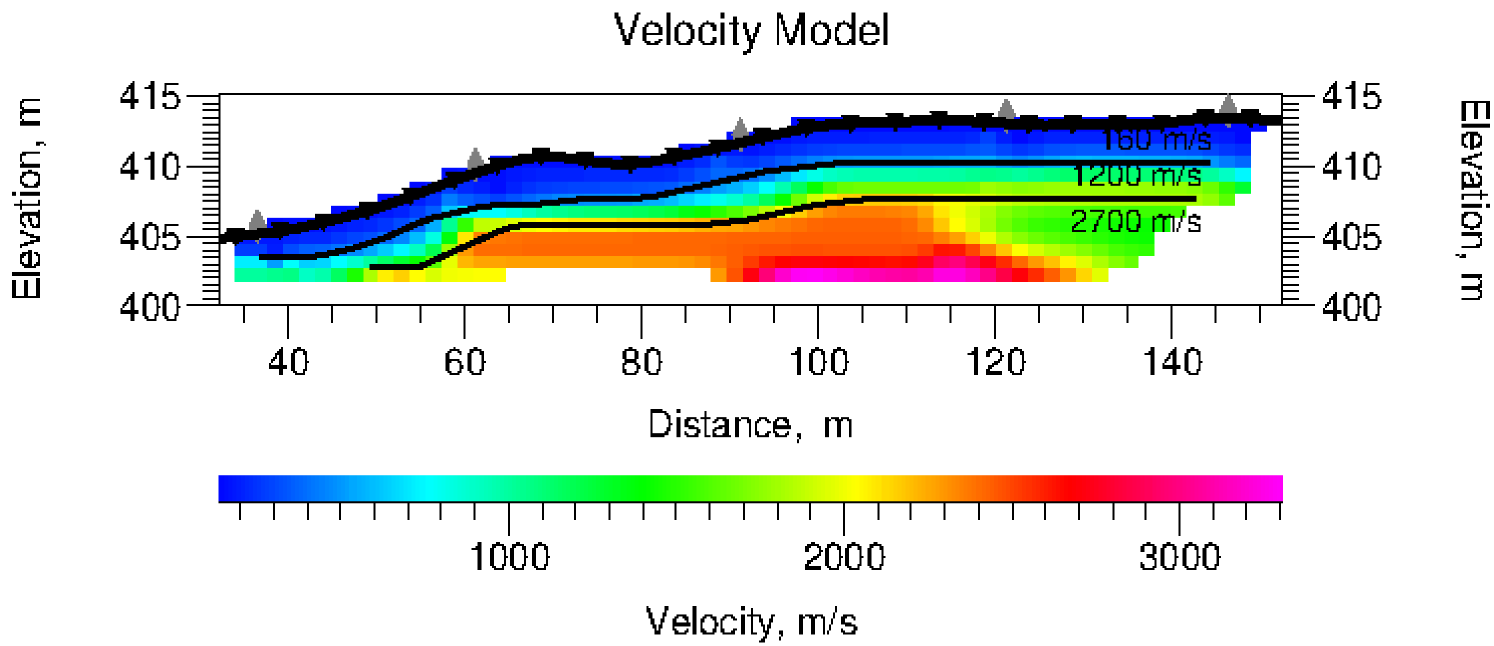
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows primarily vertical changes in resistivity values and lower values in the middle section of the profile, after a high resistivity top.

CHAINAGE 42880 (T13-P1 SIDE) ACROSS ERT W



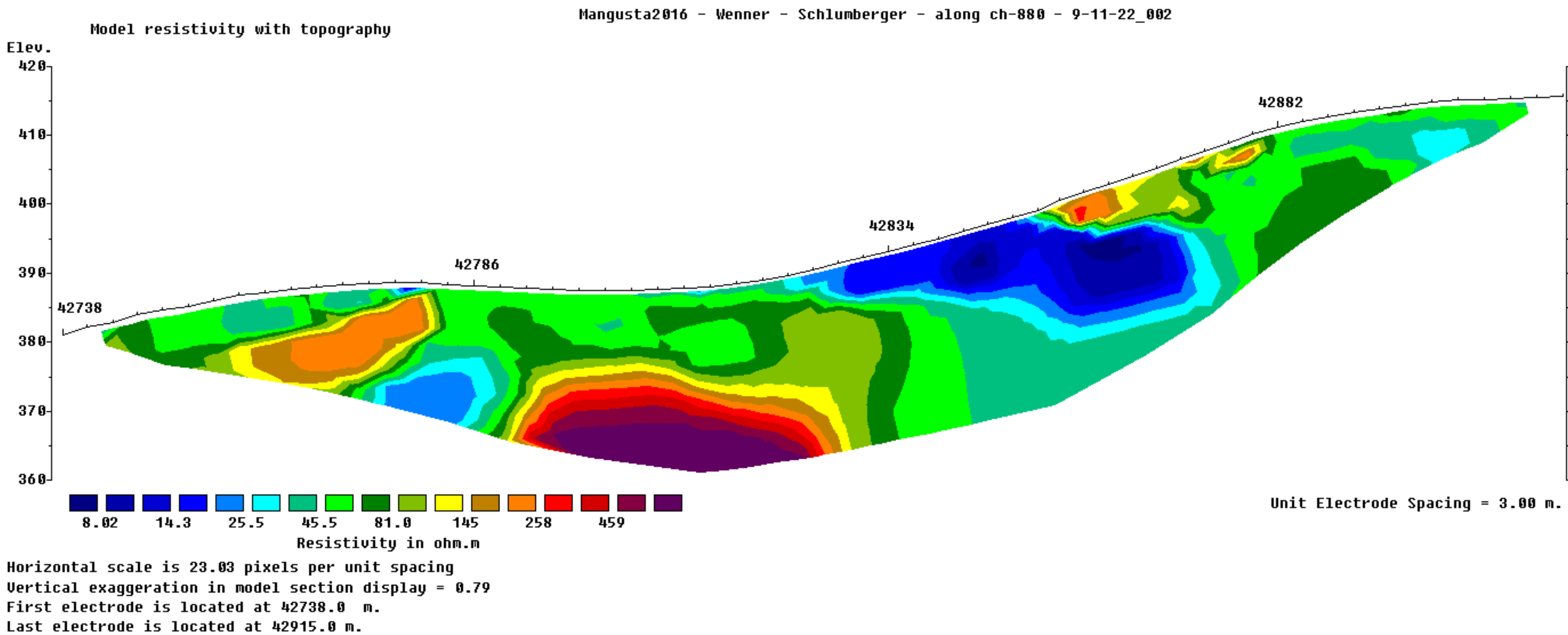
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows primarily vertical changes in resistivity values and lower values in the middle section of the profile, after a high resistivity top.

CHAINAGE 42880 (T13-P1 SIDE) ACROSS SRT



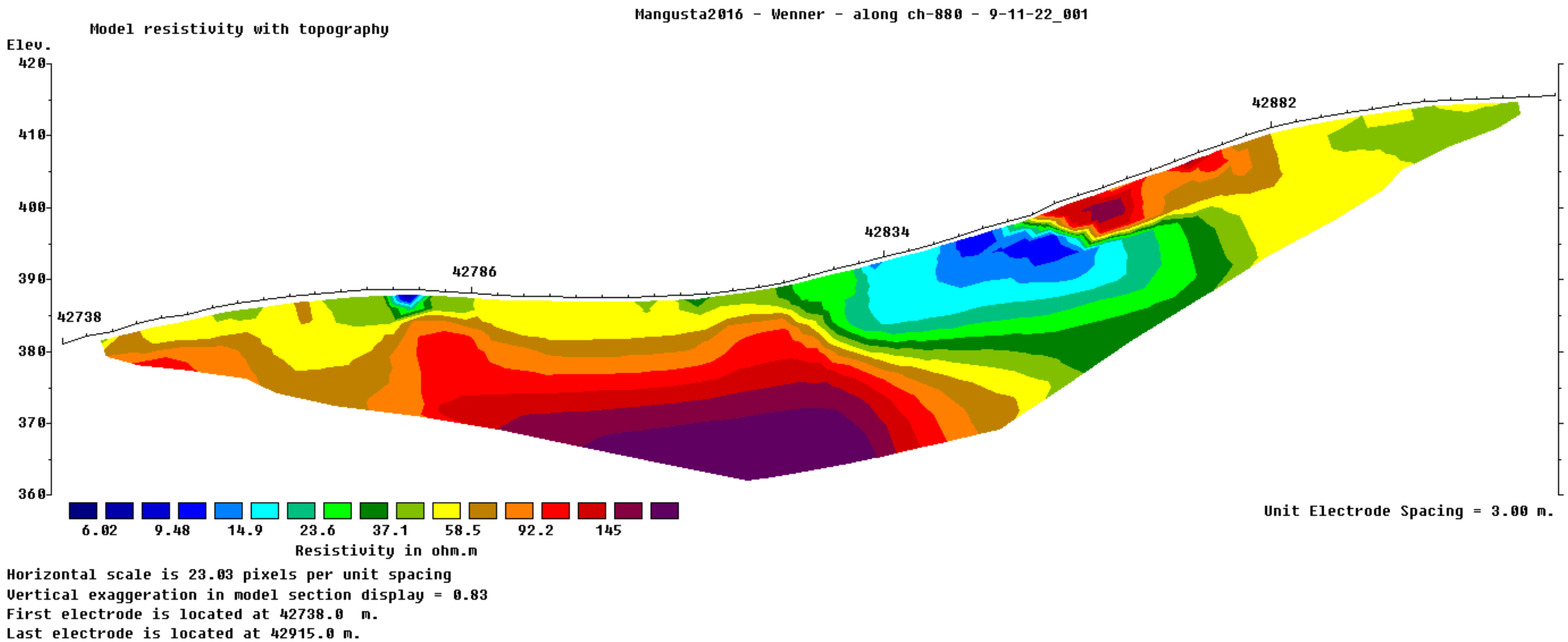
SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 1200m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 2700m/s and is likely to correspond to highly weathered rock.

CHAINAGE 42880 (T13-P1 SIDE) ALONG ERT WS



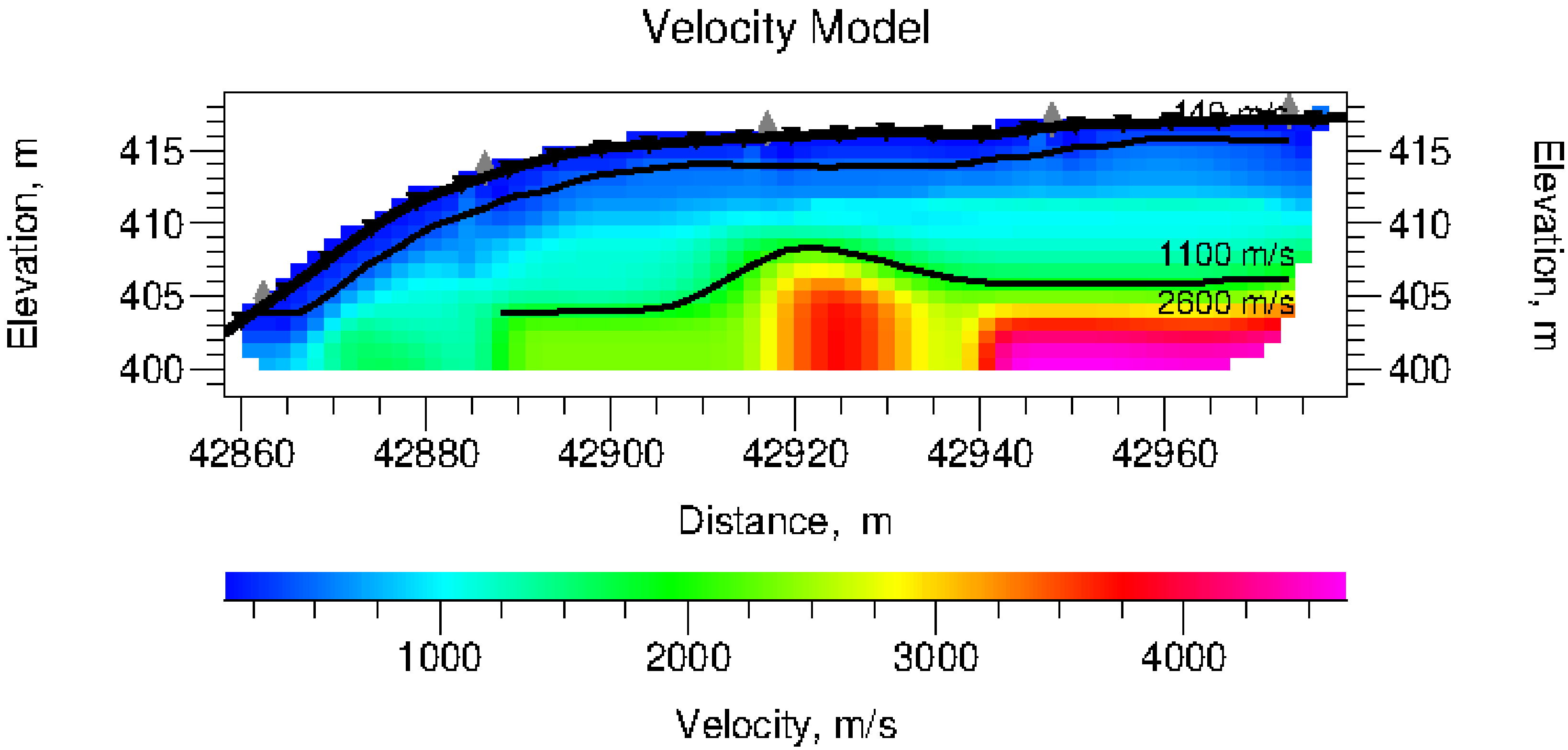
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the right section of the profile.

CHAINAGE 42880 (T13-P1 SIDE) ALONG ERT W



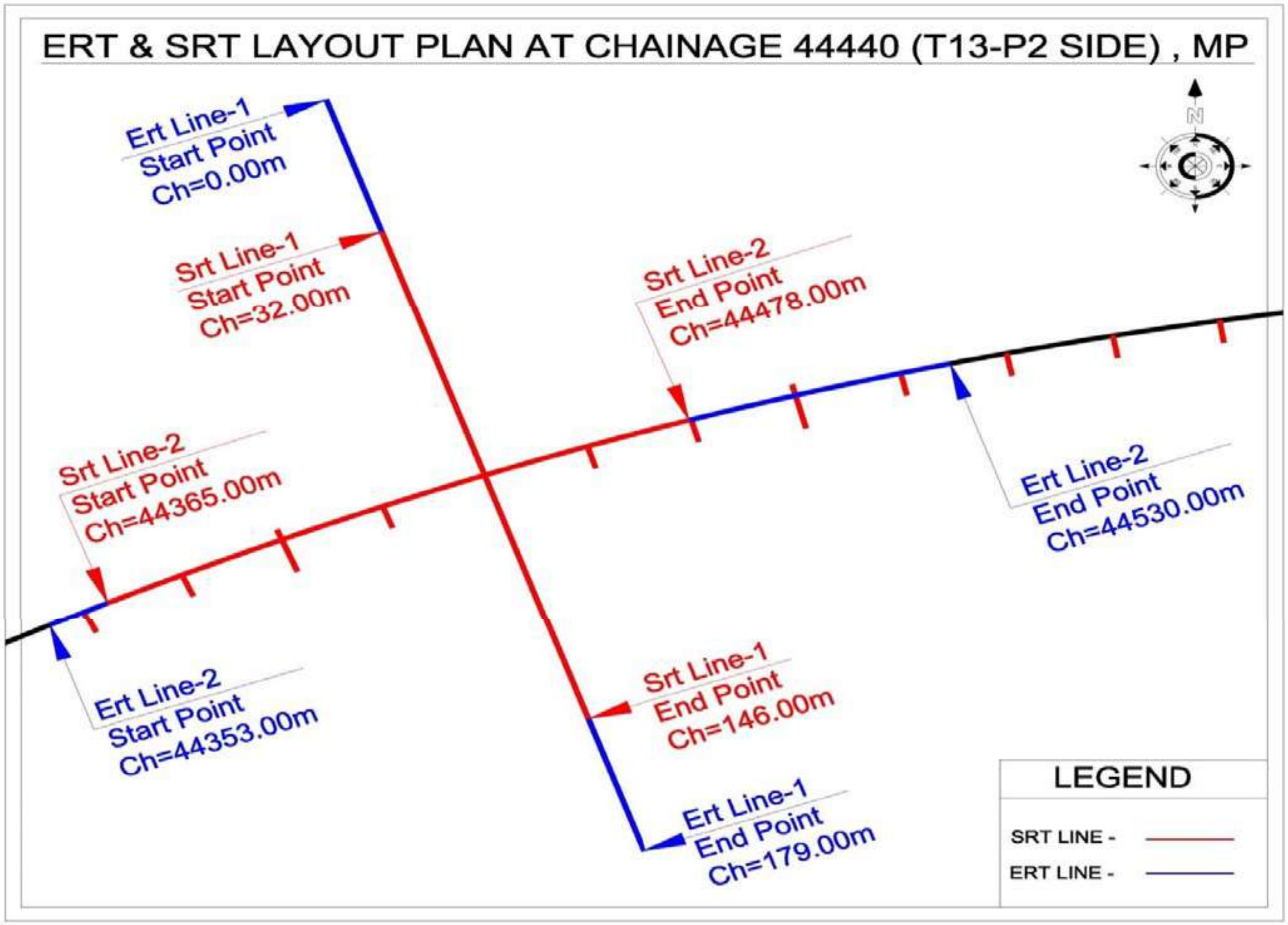
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the right section of the profile.

CHAINAGE 42880 (T13-P1 SIDE) ALONG SRT

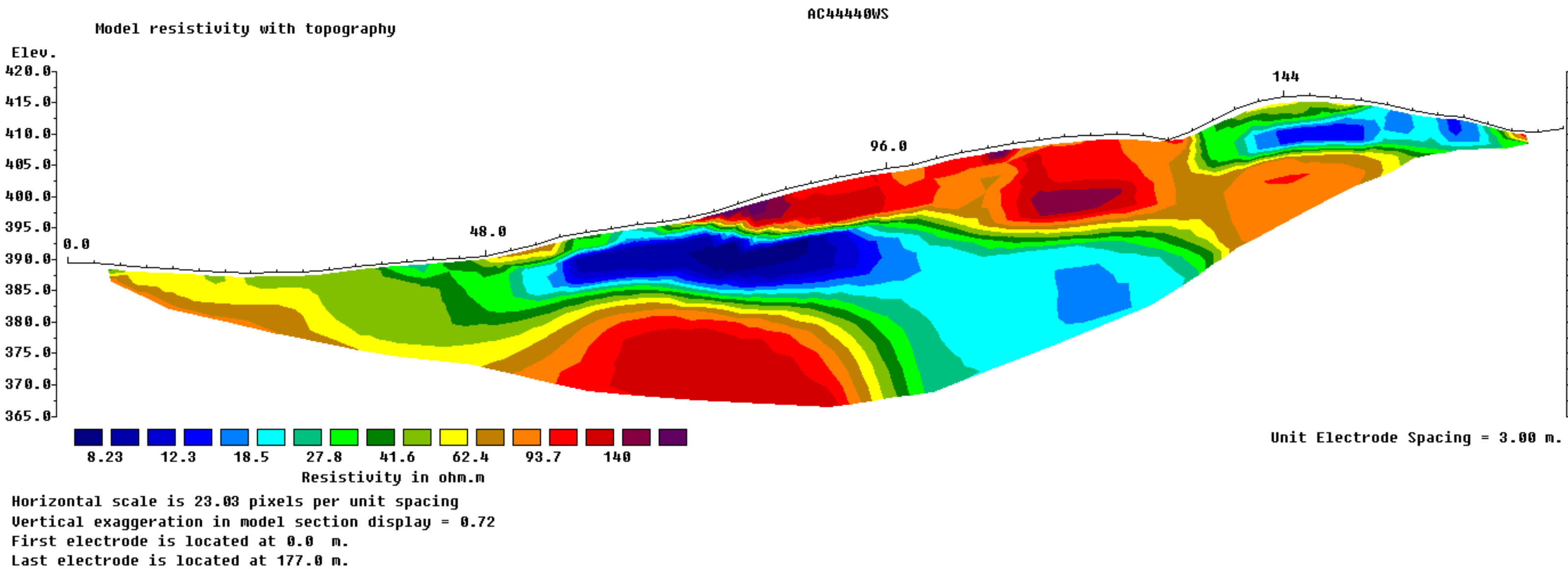


SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 1100m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 2600m/s and is likely to correspond to highly weathered rock.

ERT & SRT LAYOUT PLAN AT CHAINAGE 44440 (T13-P2 SIDE)

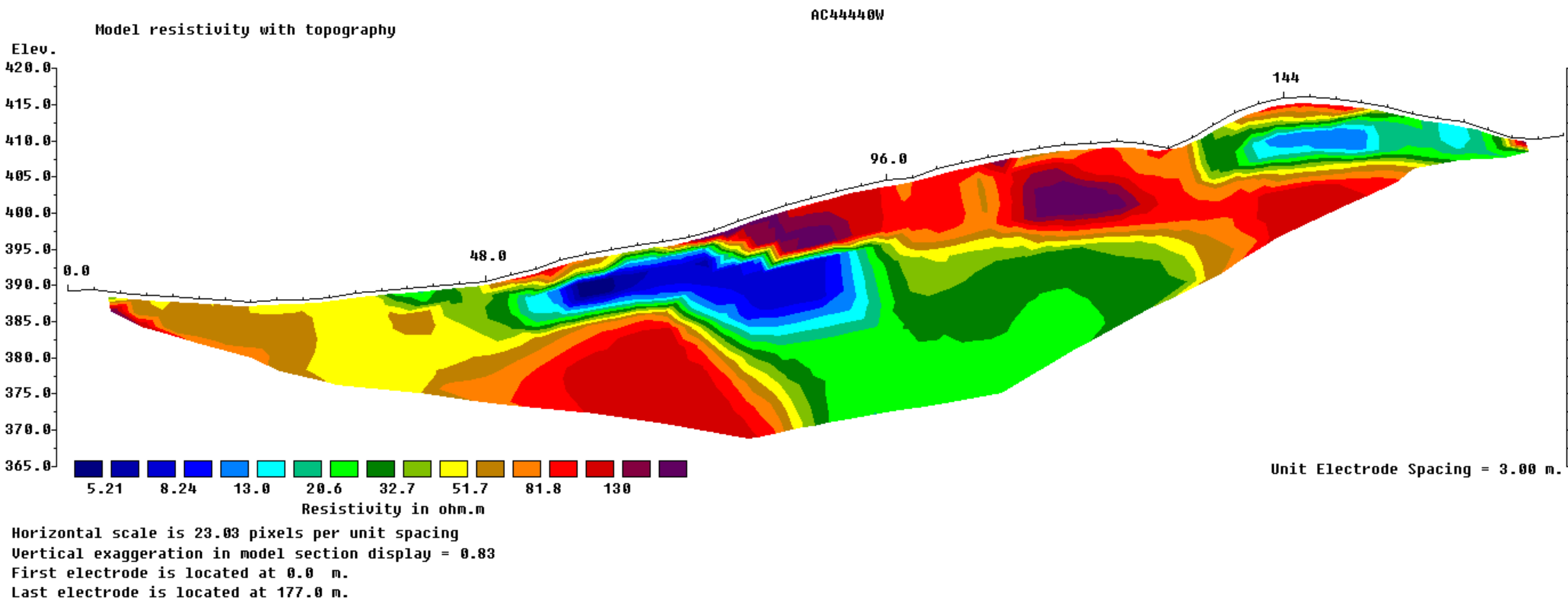


CHAINAGE 44440 (T13-P2 SIDE) ACROSS ERT-WS



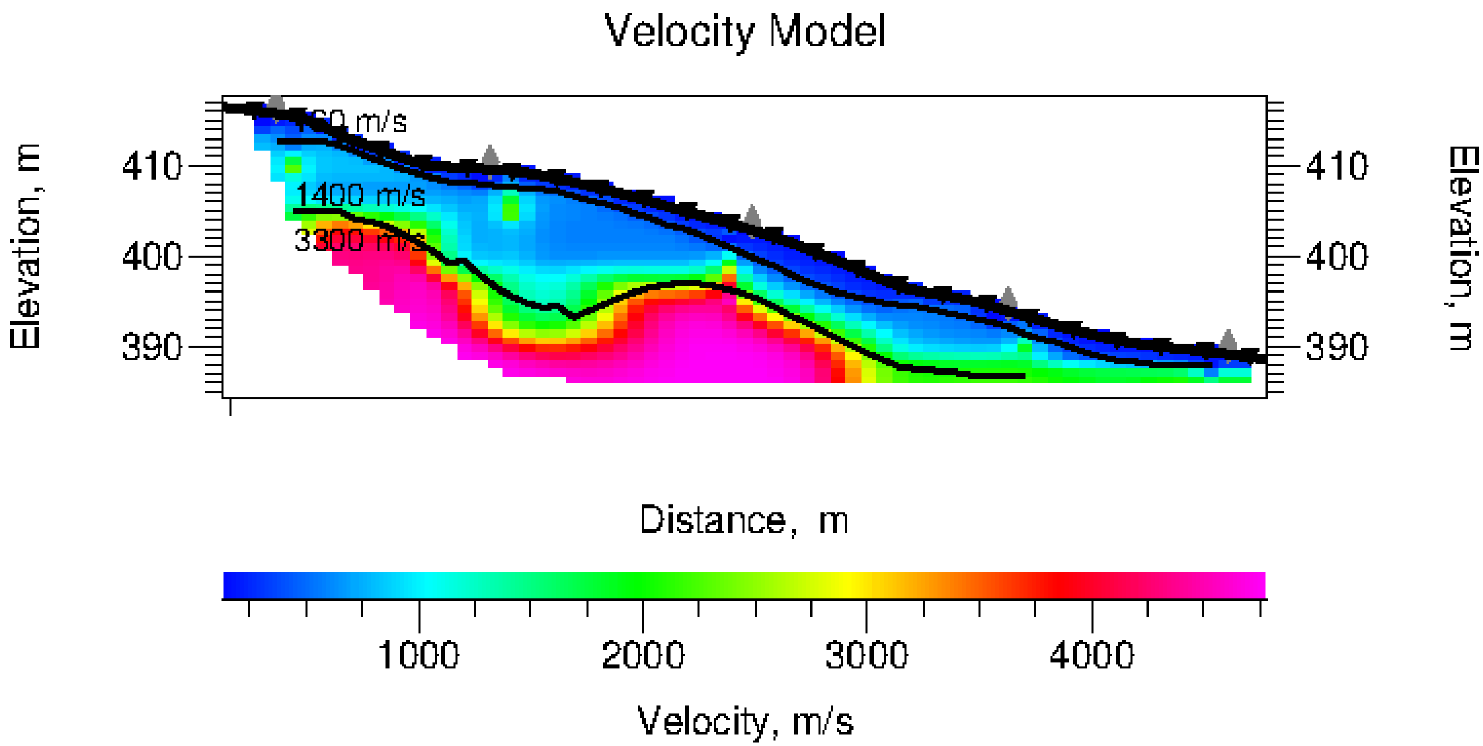
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the center-right of the profile.

CHAINAGE 44440 (T13-P2 SIDE) ACROSS ERT-W



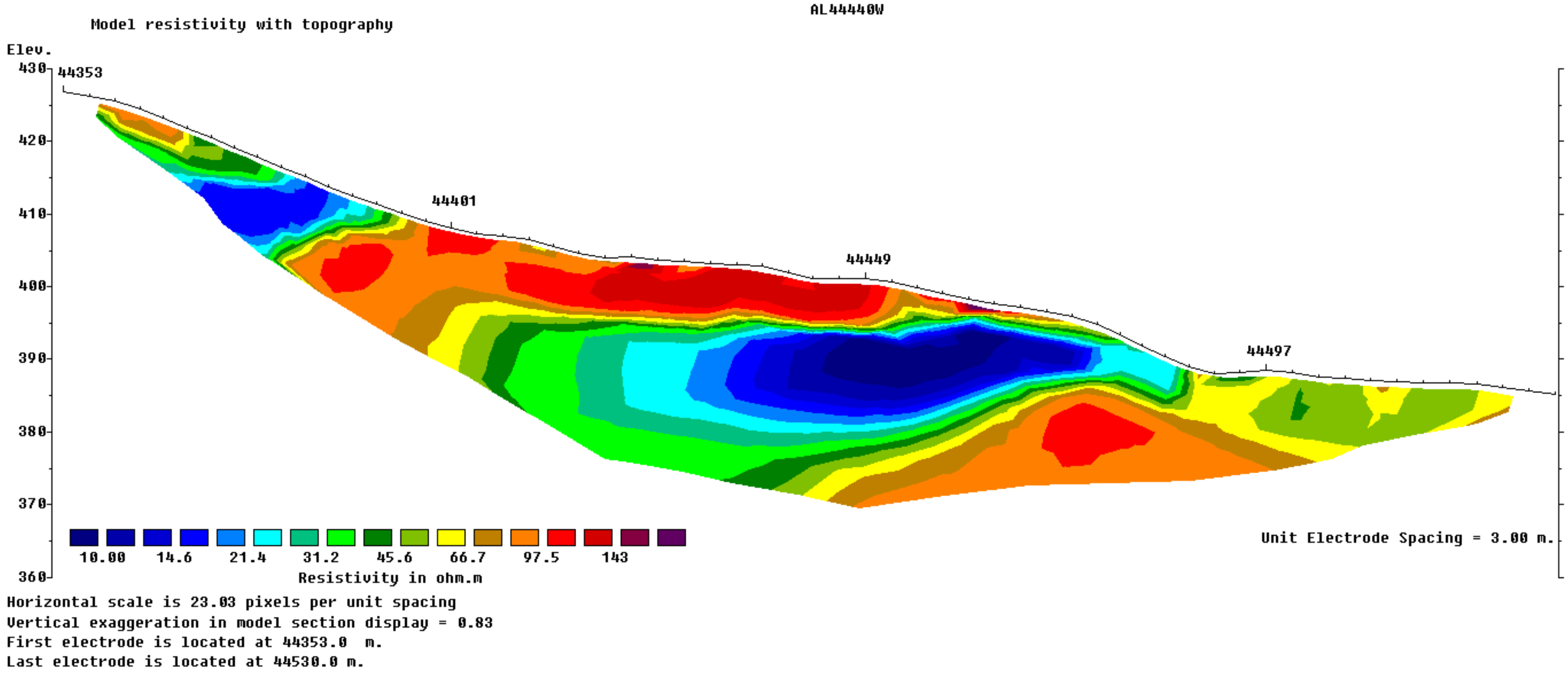
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the center-right of the profile.

CHAINAGE 44440 (T13-P2 SIDE) ACROSS SRT



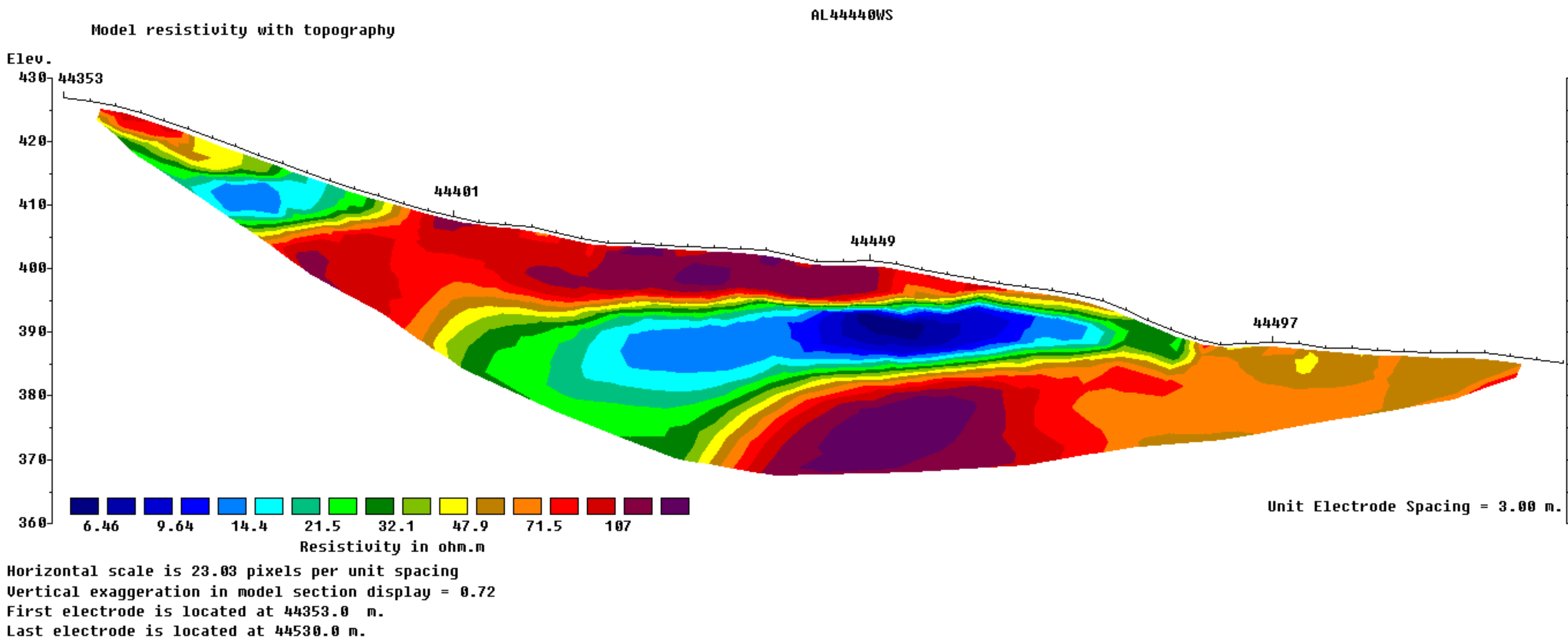
SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 1400m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 3300m/s and is likely to correspond to highly weathered rock.

CHAINAGE 44440 (T13-P2 SIDE)ALONG ERT-W



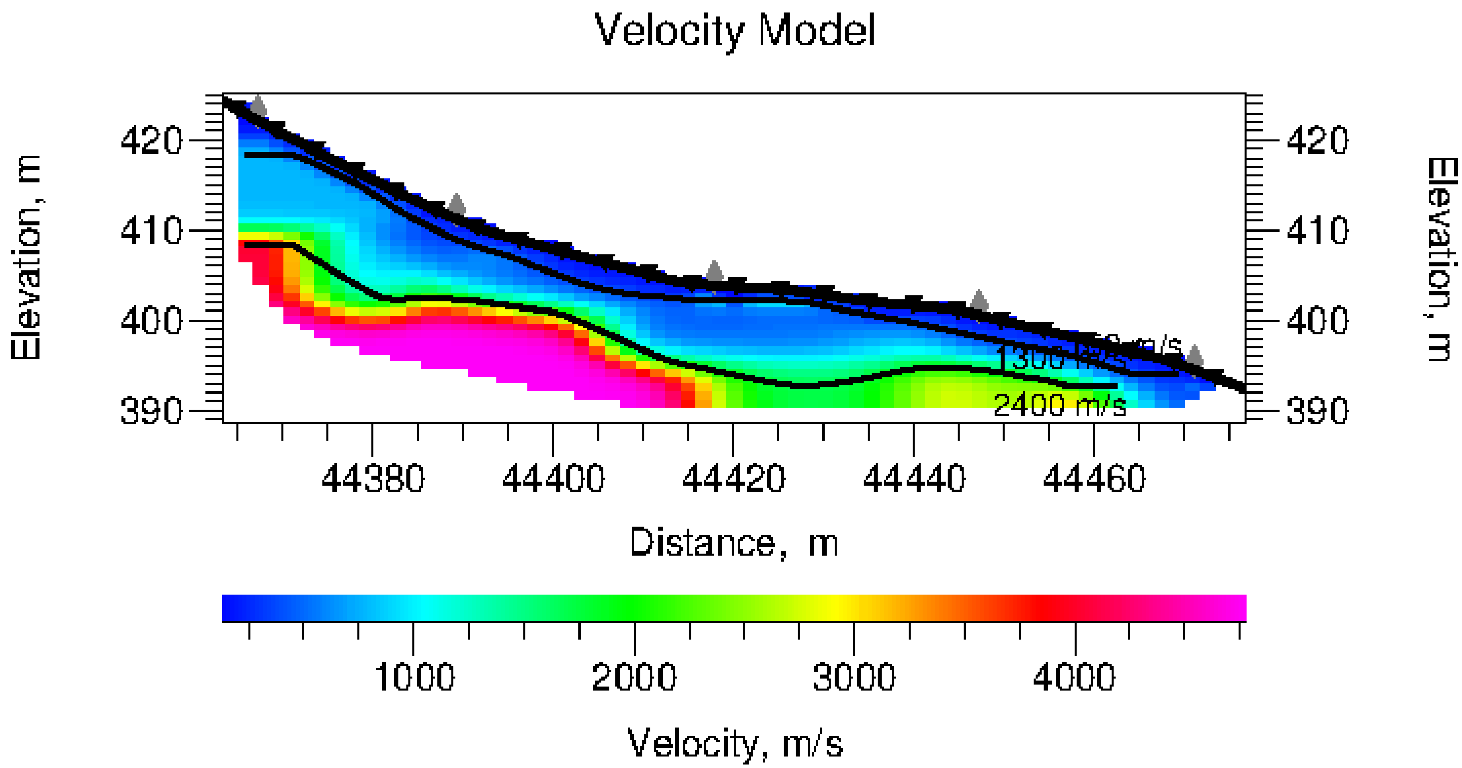
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the center of the profile.

CHAINAGE 44440 (T13-P2 SIDE)ALONG ERT-WS



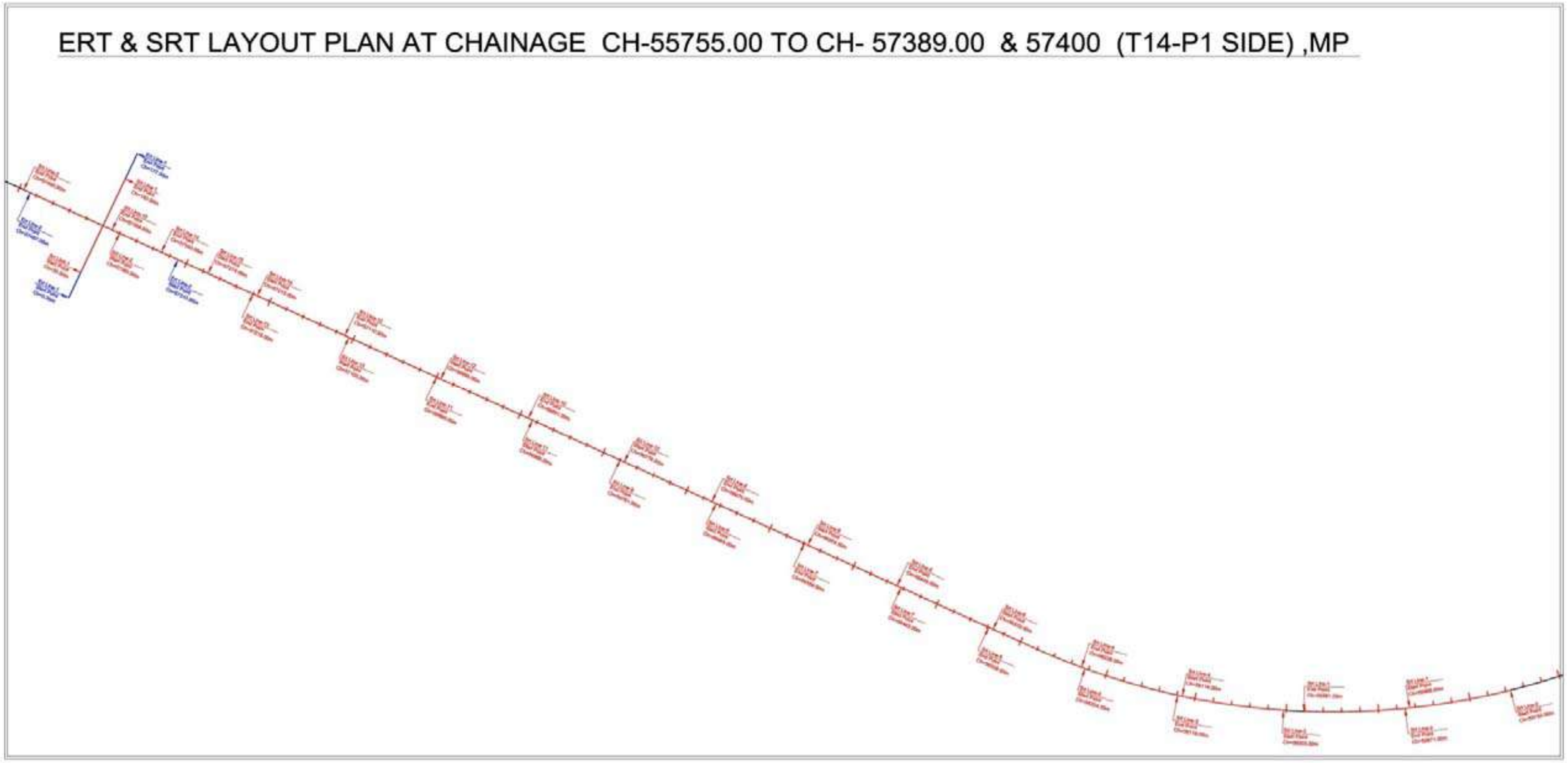
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the center of the profile.

CHAINAGE 44440 (T13-P2 SIDE)ALONG SRT

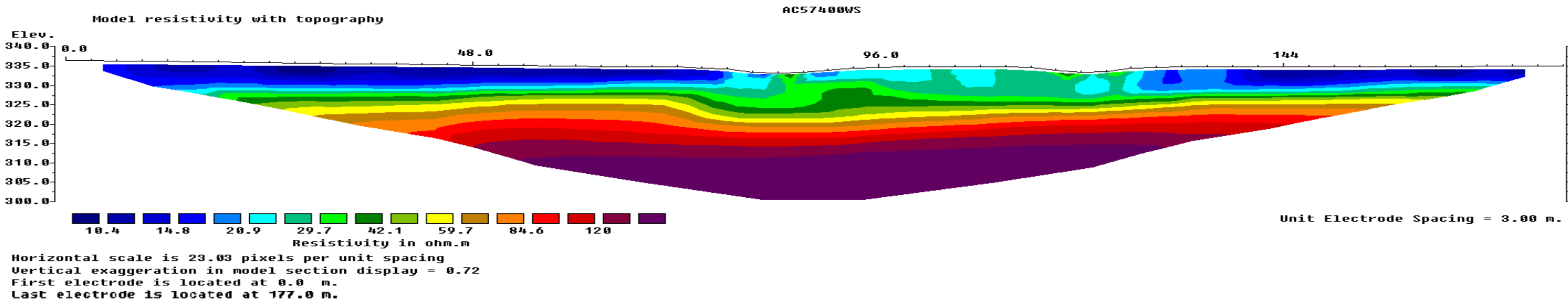


SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 1300m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 2400m/s and is likely to correspond to highly weathered rock.

ERT & SRT LAYOUT PLAN AT CHAINAGE CH-55755.00 TO CH- 57389 & 57400(T 14 –P1 SIDE)

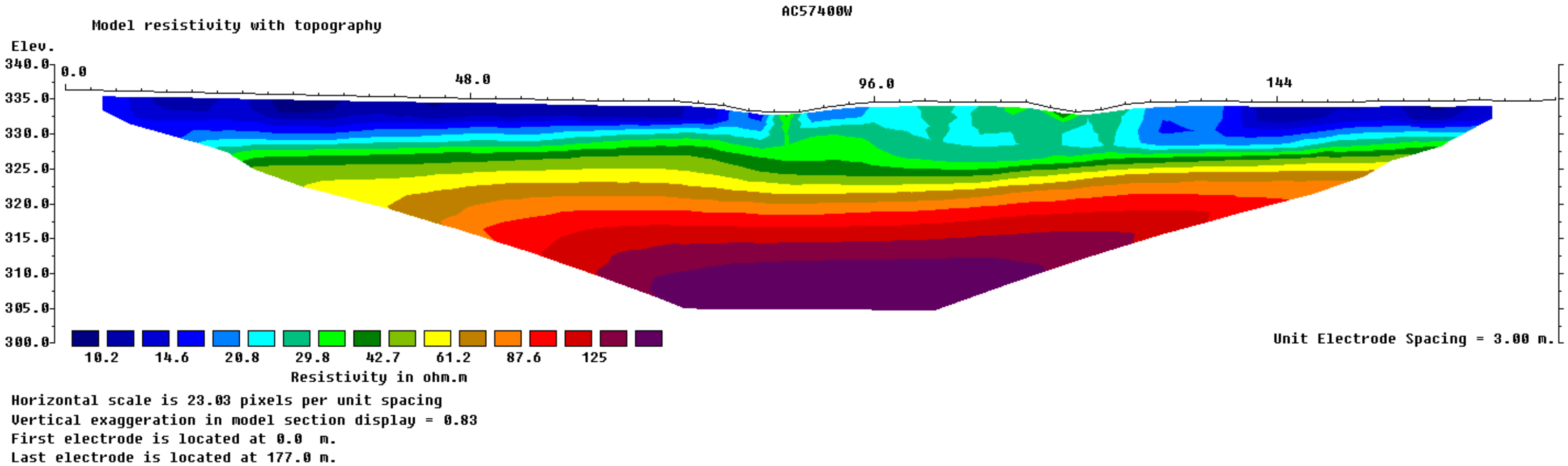


CHAINAGE 57400 ACROSS ERT WS



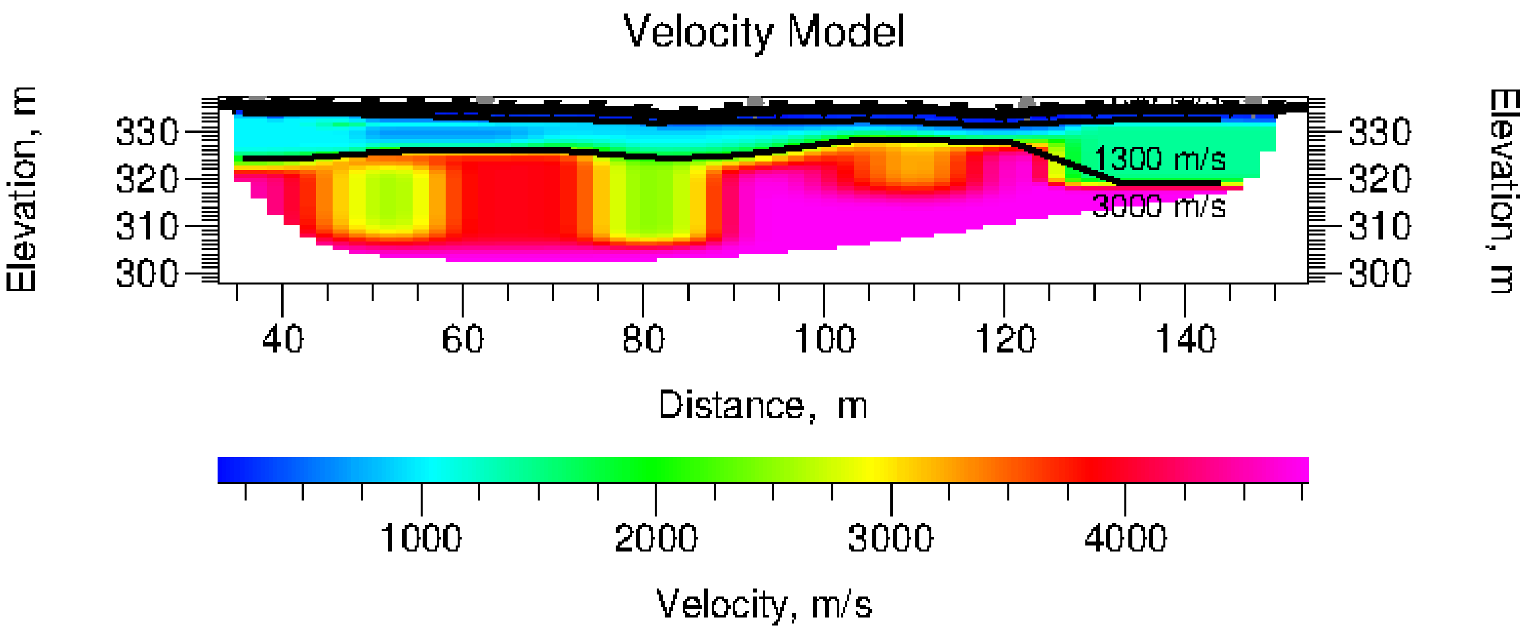
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows vertical changes in resistivity values and lower values in the top section of the profile.

CHAINAGE 57400 ACROSS ERT W



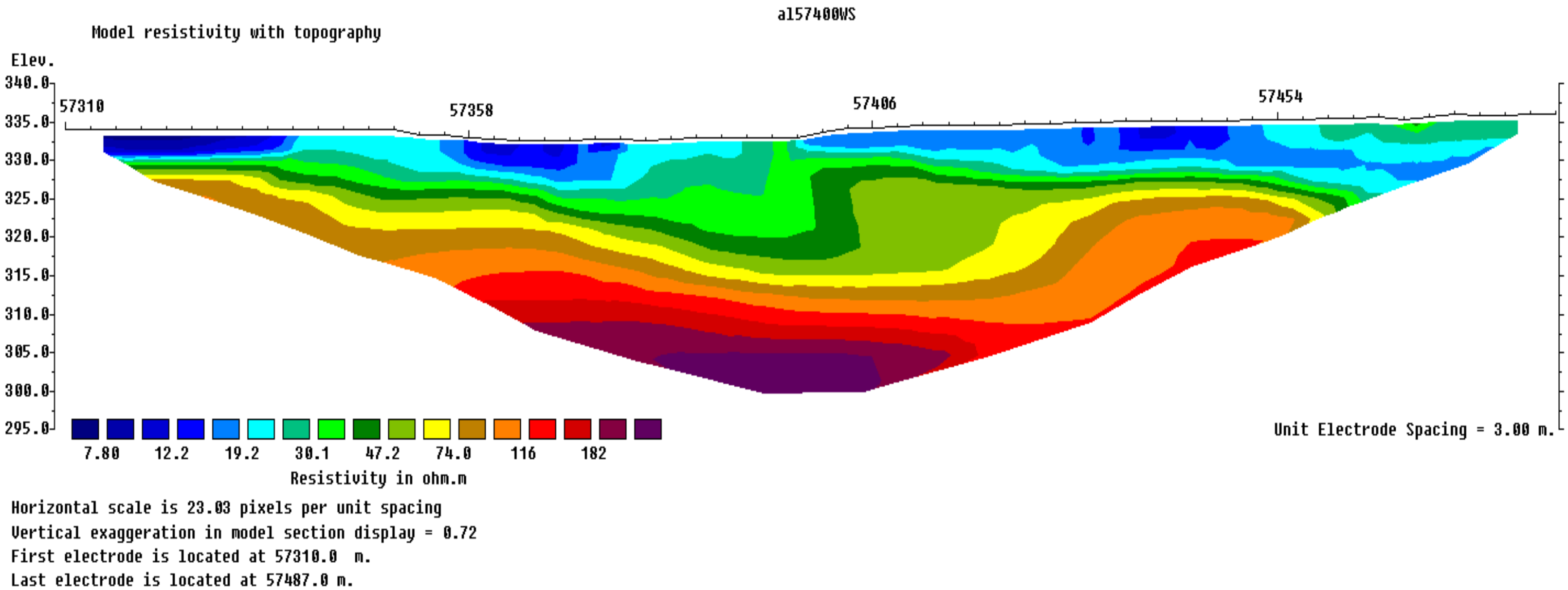
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows vertical changes in resistivity values and lower values in the top section of the profile.

CHAINAGE 57400 ACROSS SRT



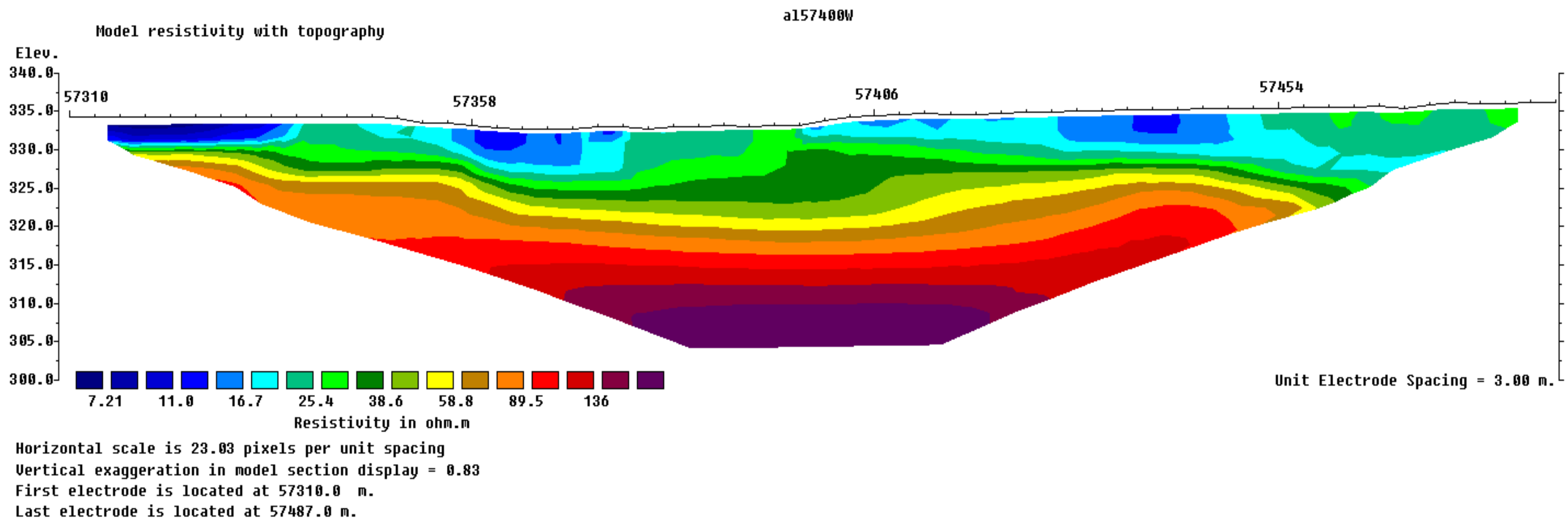
SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 1300m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 3000m/s and is likely to correspond to highly weathered rock.

CHAINAGE 57400 ALONG ERT WS



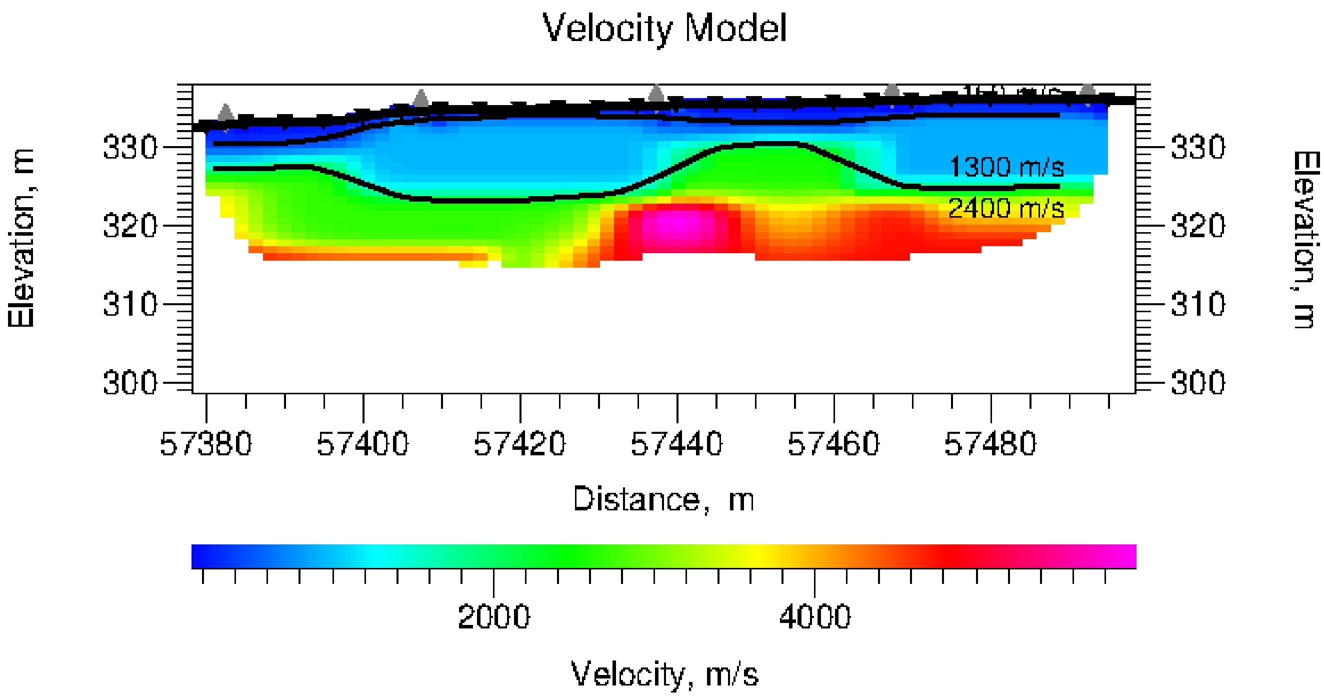
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows vertical changes in resistivity values and lower values in the top section of the profile.

CHAINAGE 57400 ALONG ERT W



Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows vertical changes in resistivity values and lower values in the top section of the profile.

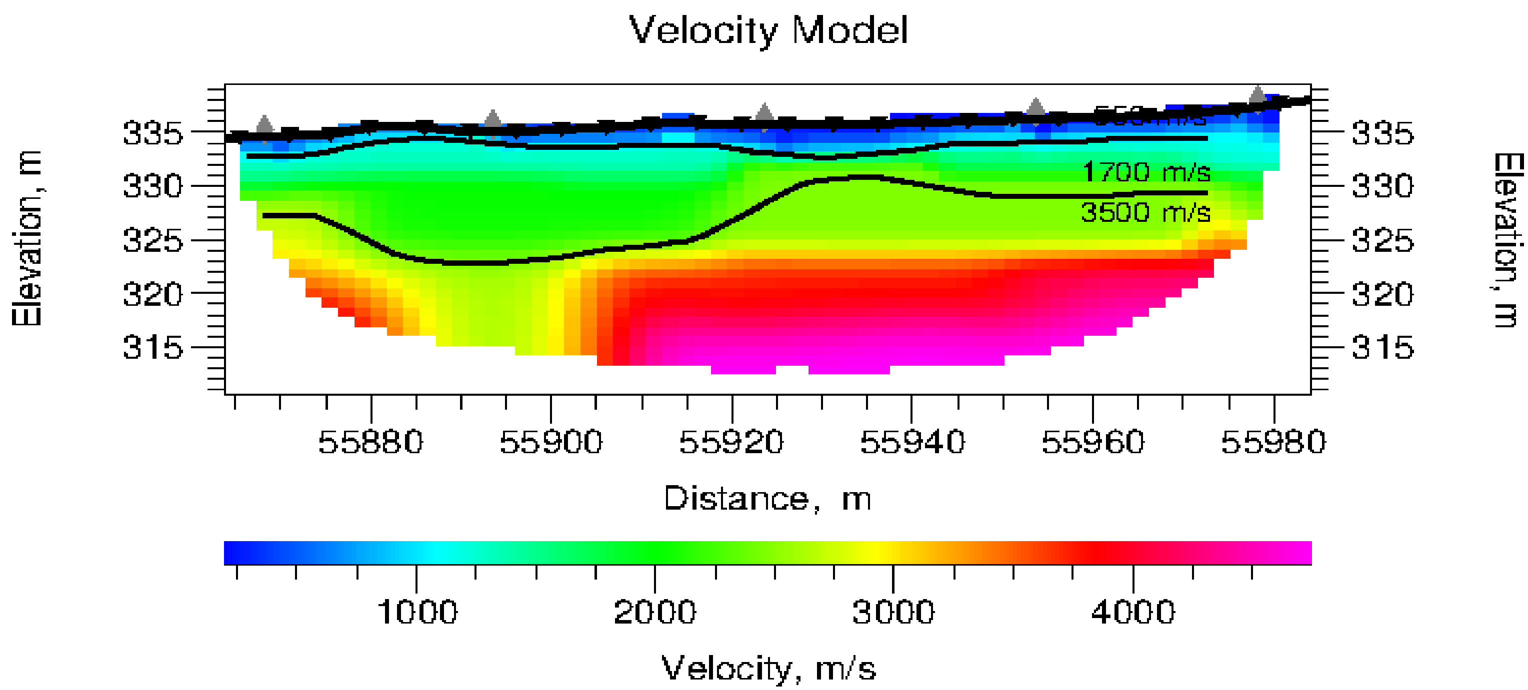
CHAINAGE 57400 ALONG SRT



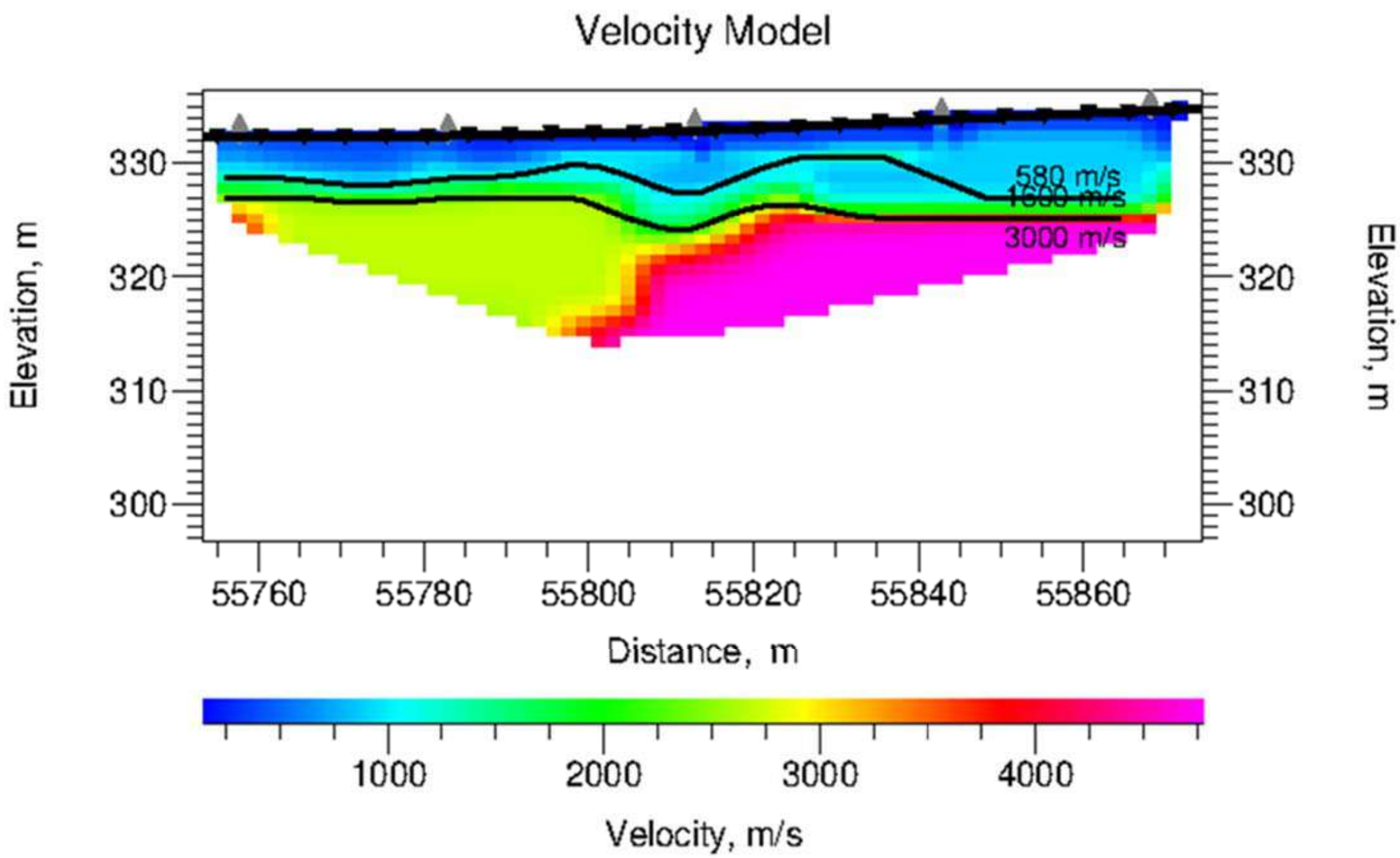
SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 1300m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 2400m/s and is likely to correspond to highly weathered rock.

CHAINAGE CH-55755.00 TO CH- 57389 (T 14 –P1 SIDE)

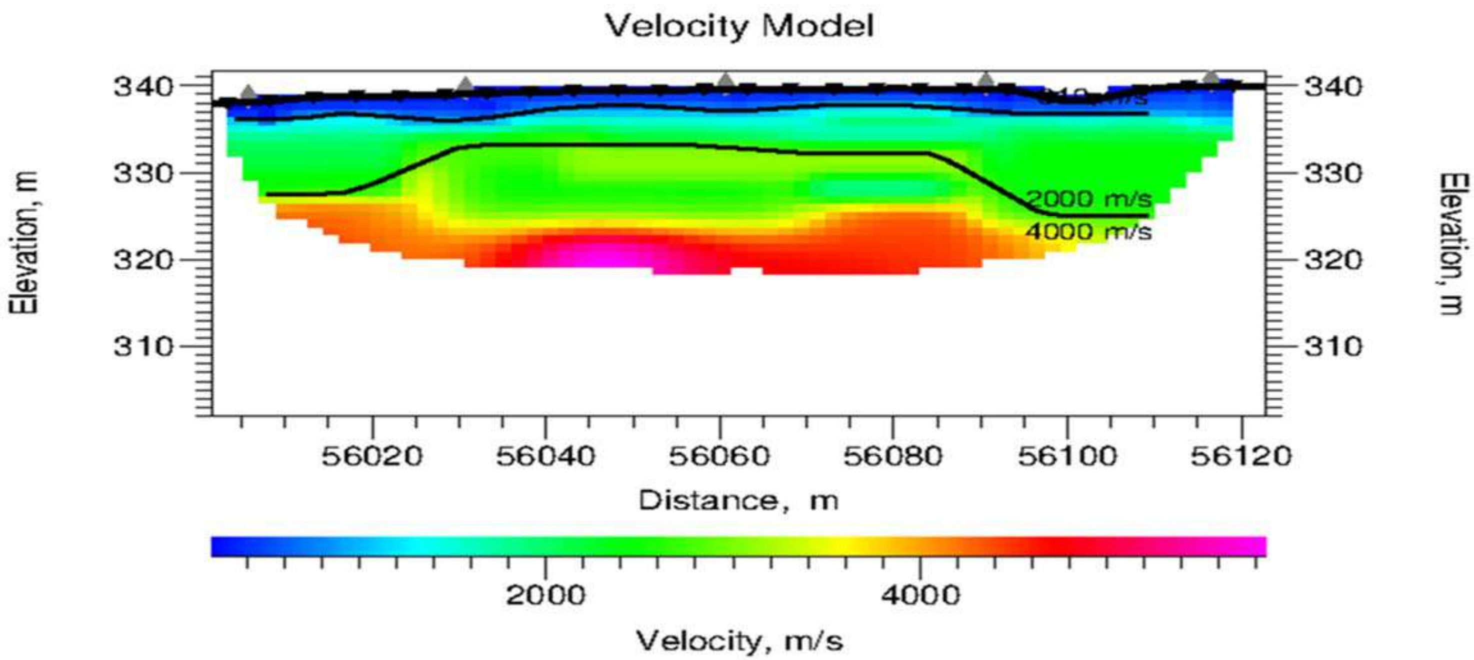
DEEP CUTTING 1600 SRT



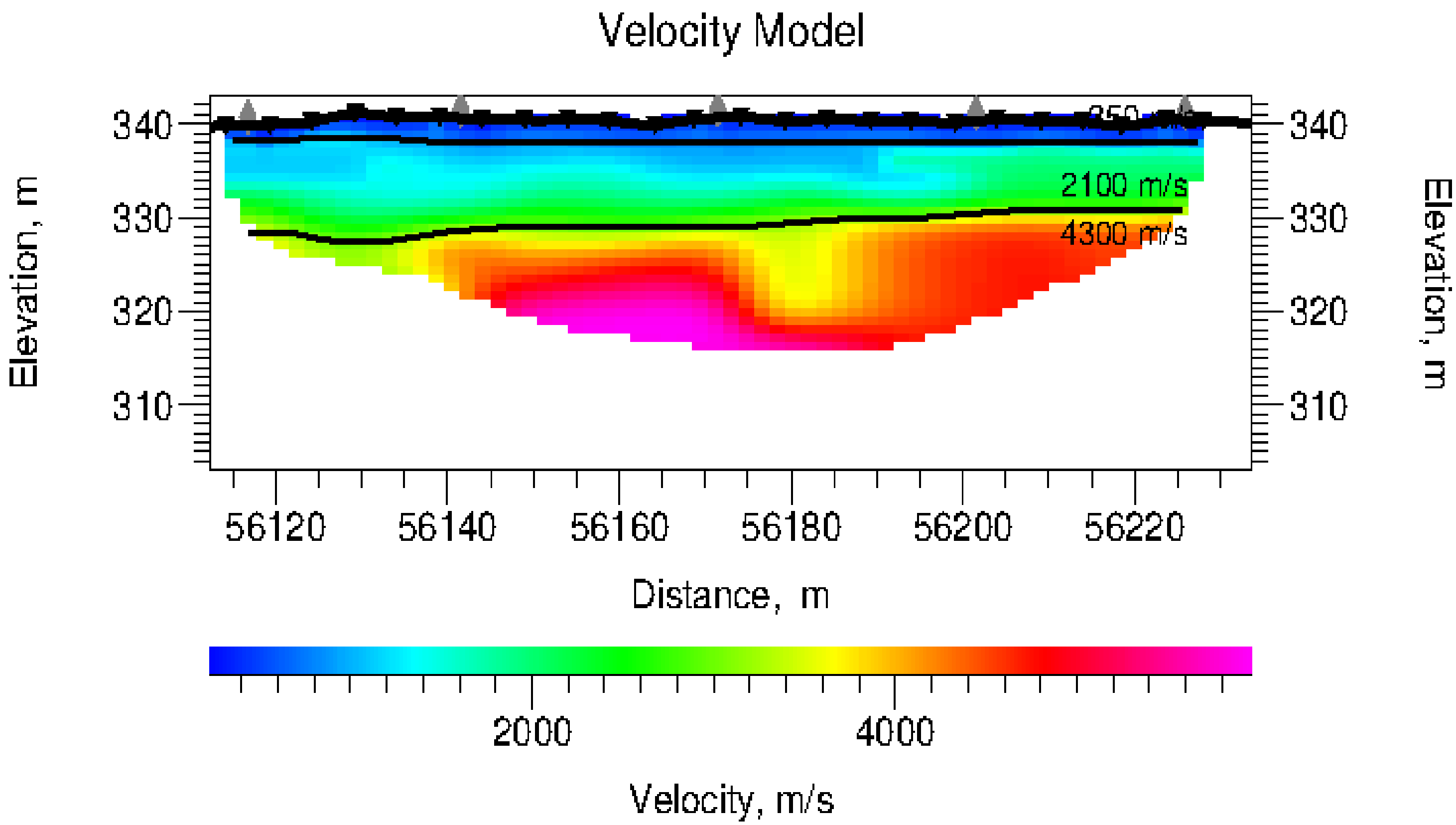
SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 1700m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 3500m/s and is likely to correspond to slightly to highly weathered rock.



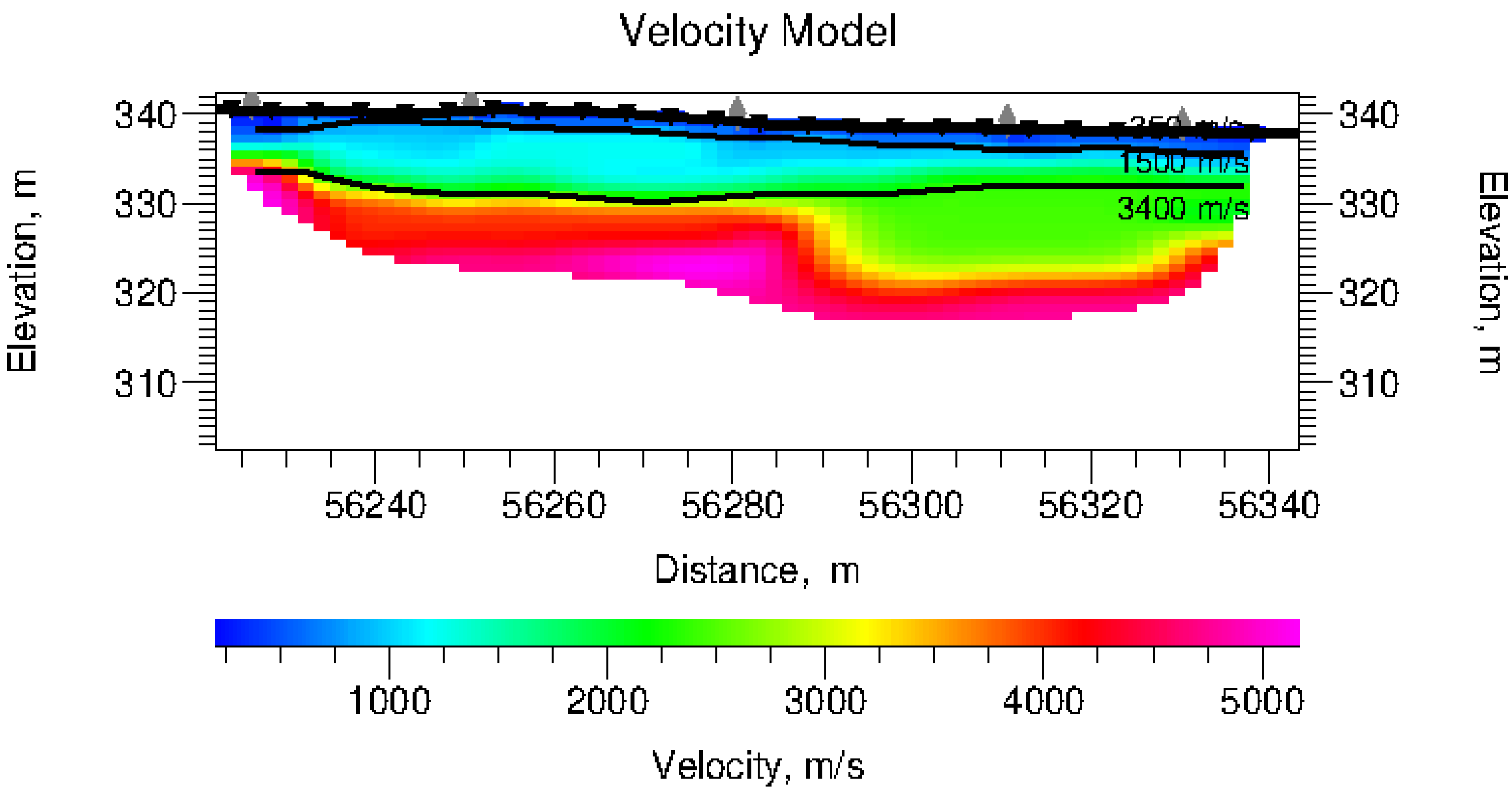
SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <600m/s represents top overburden. The second layer has P wave velocity of approximately 1600m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 3000m/s and is likely to correspond to highly weathered rock.



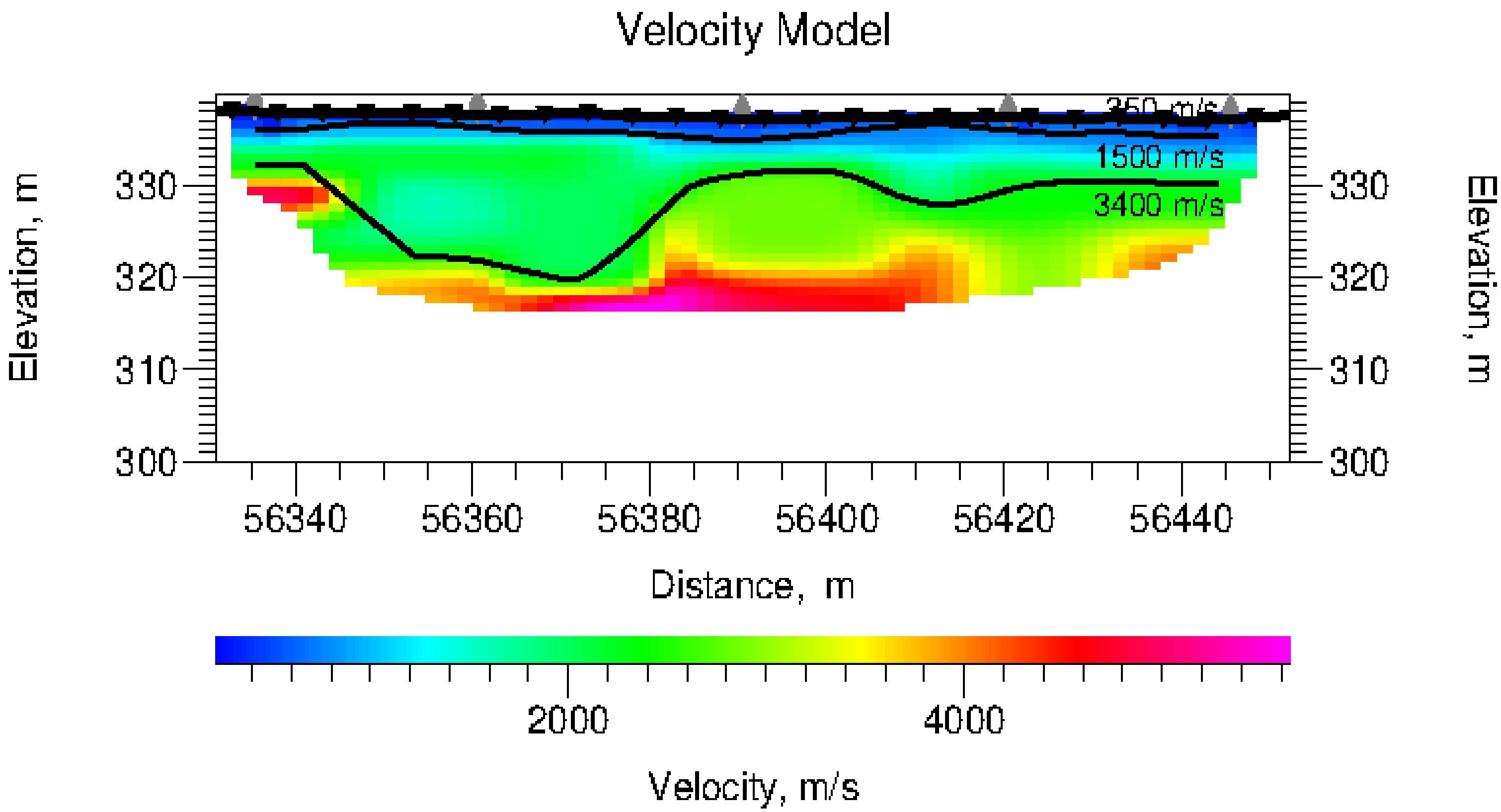
SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 2000m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 4000m/s and is likely to correspond to slightly to highly weathered rock.



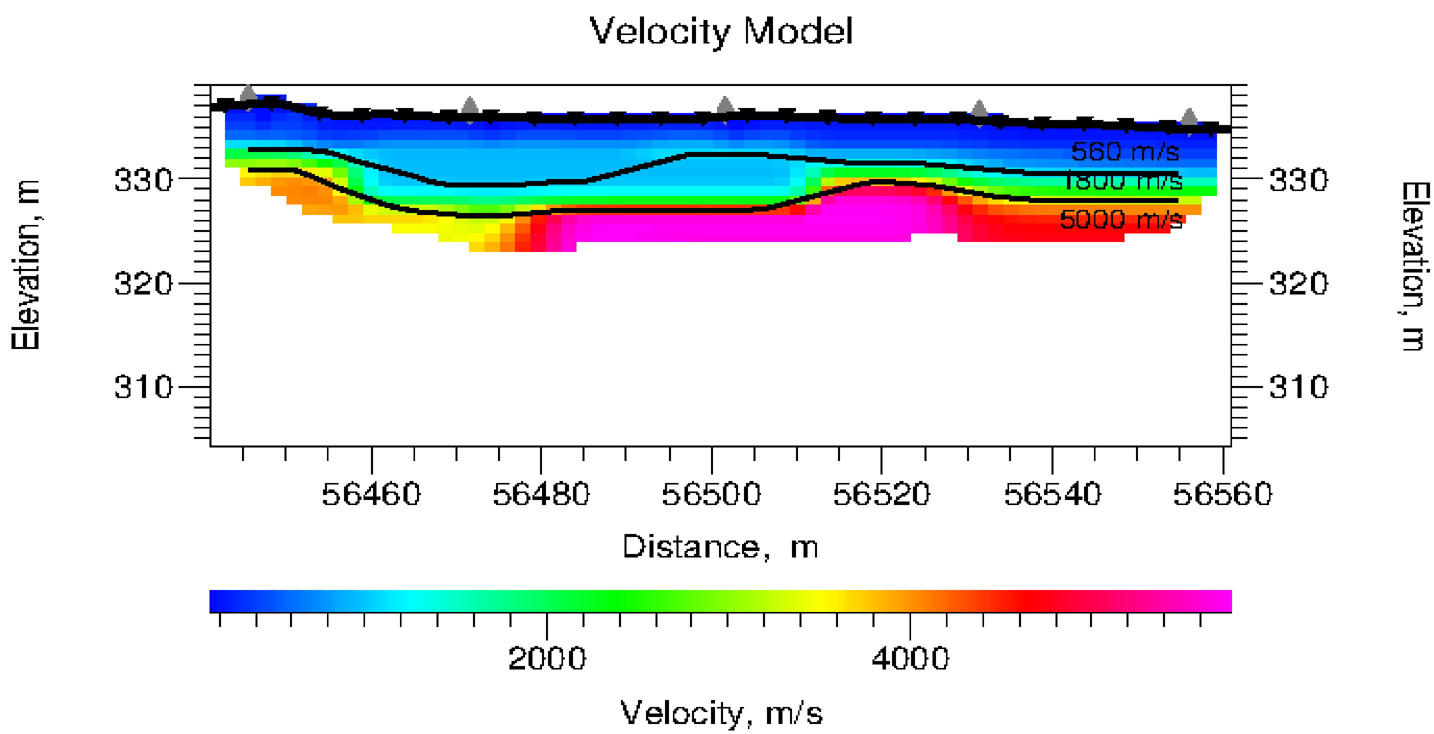
SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 2100m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 4300m/s and is likely to correspond to slightly weathered rock.



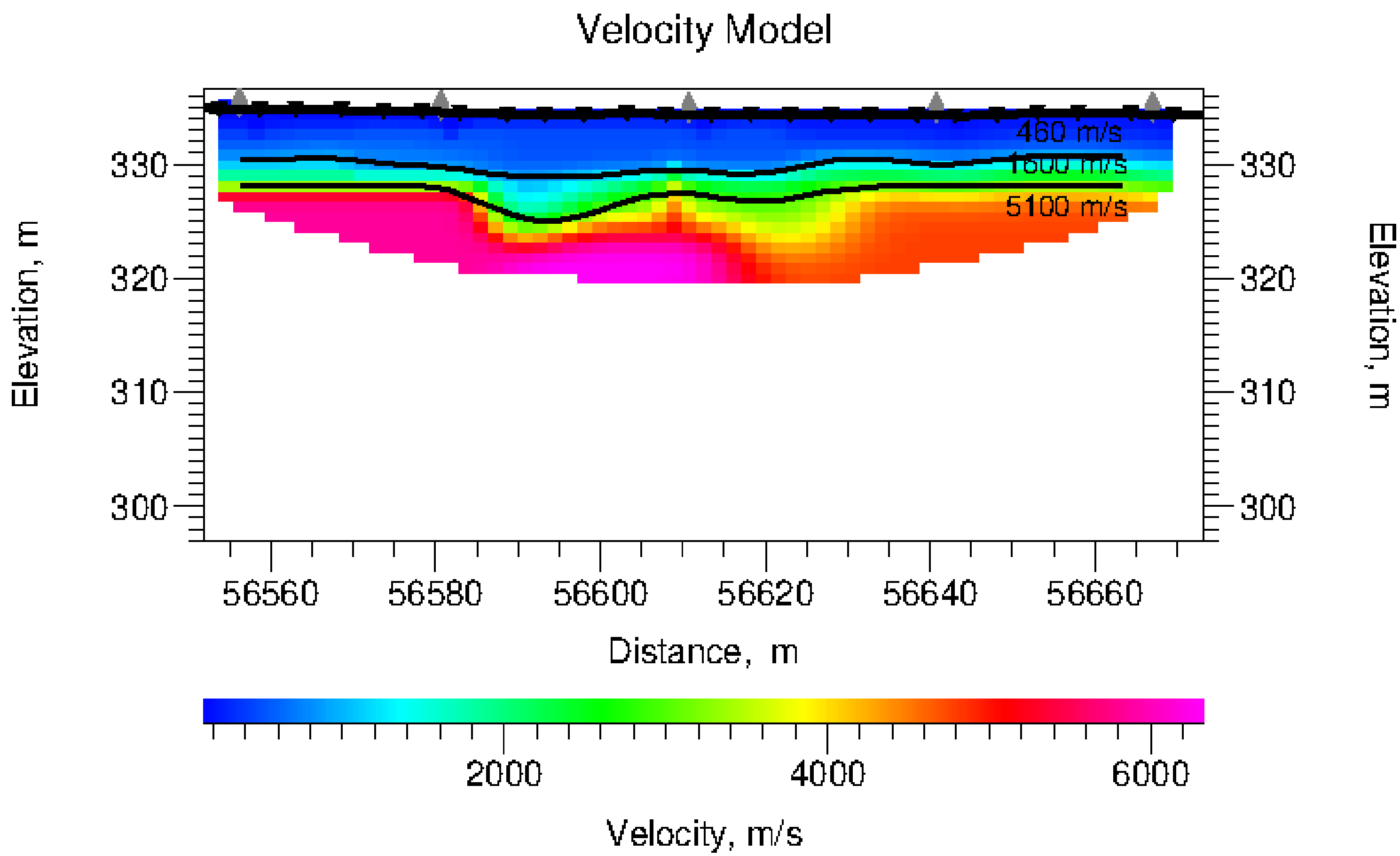
SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 1500m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 3400m/s and is likely to correspond to slightly to highly weathered rock.



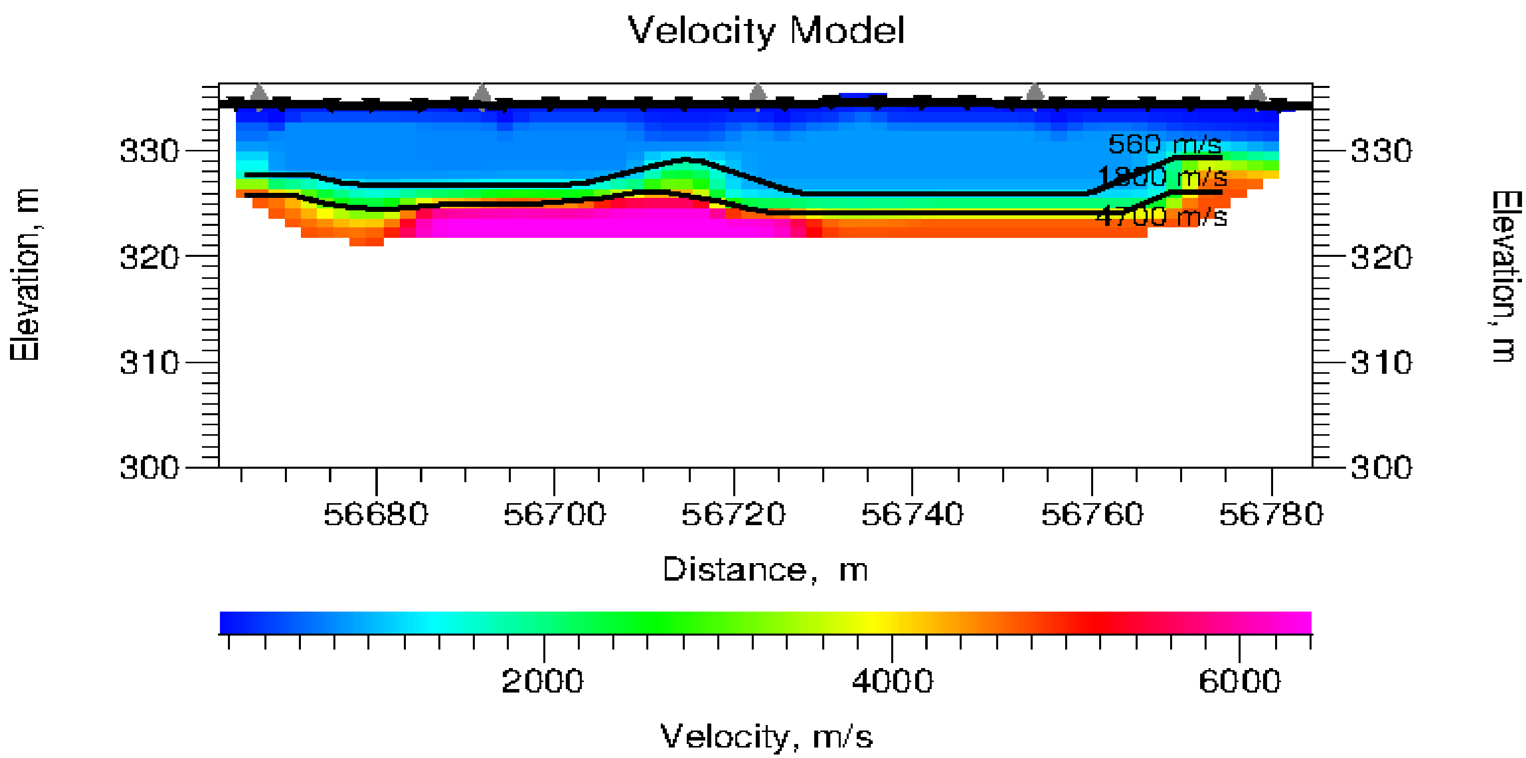
SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 1500m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 3400m/s and is likely to correspond to slightly to highly weathered rock.



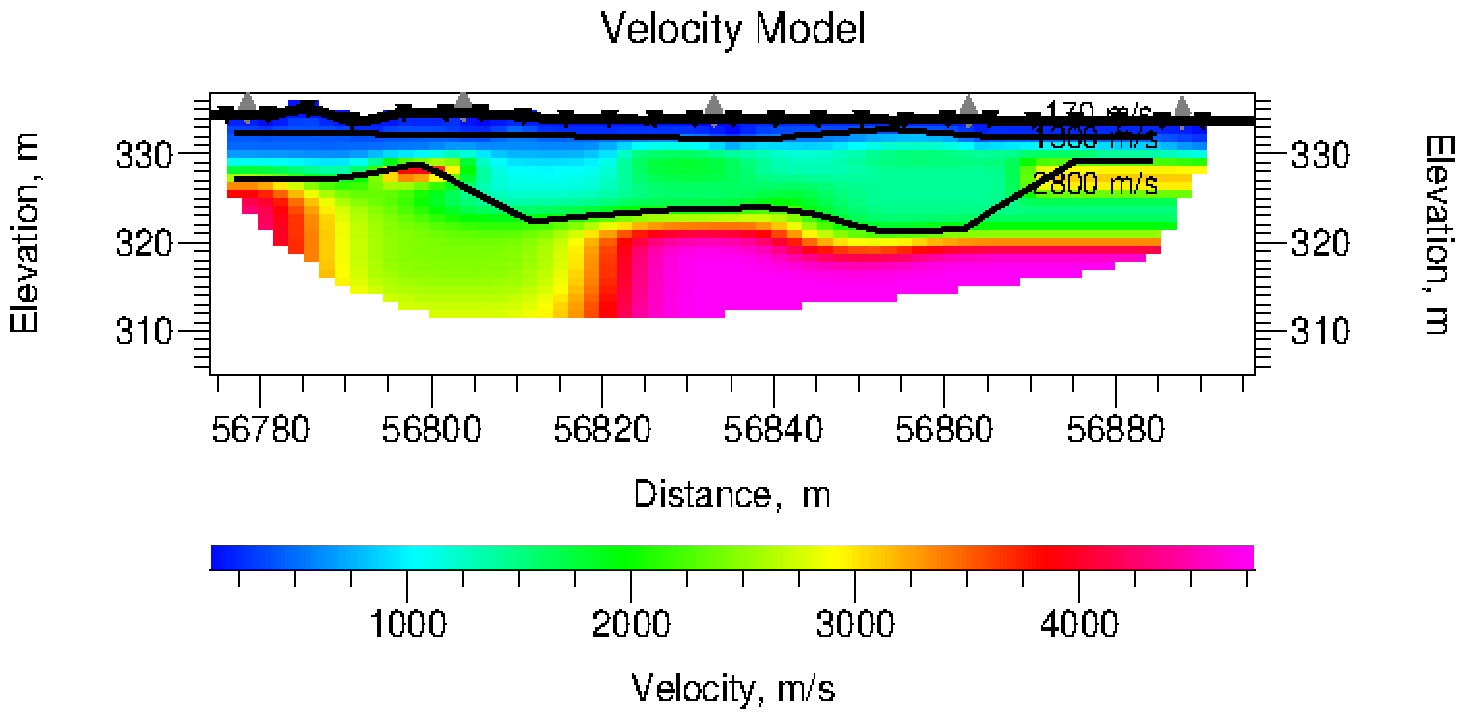
SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 1800m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 5000m/s and is likely to correspond to fresh rock.



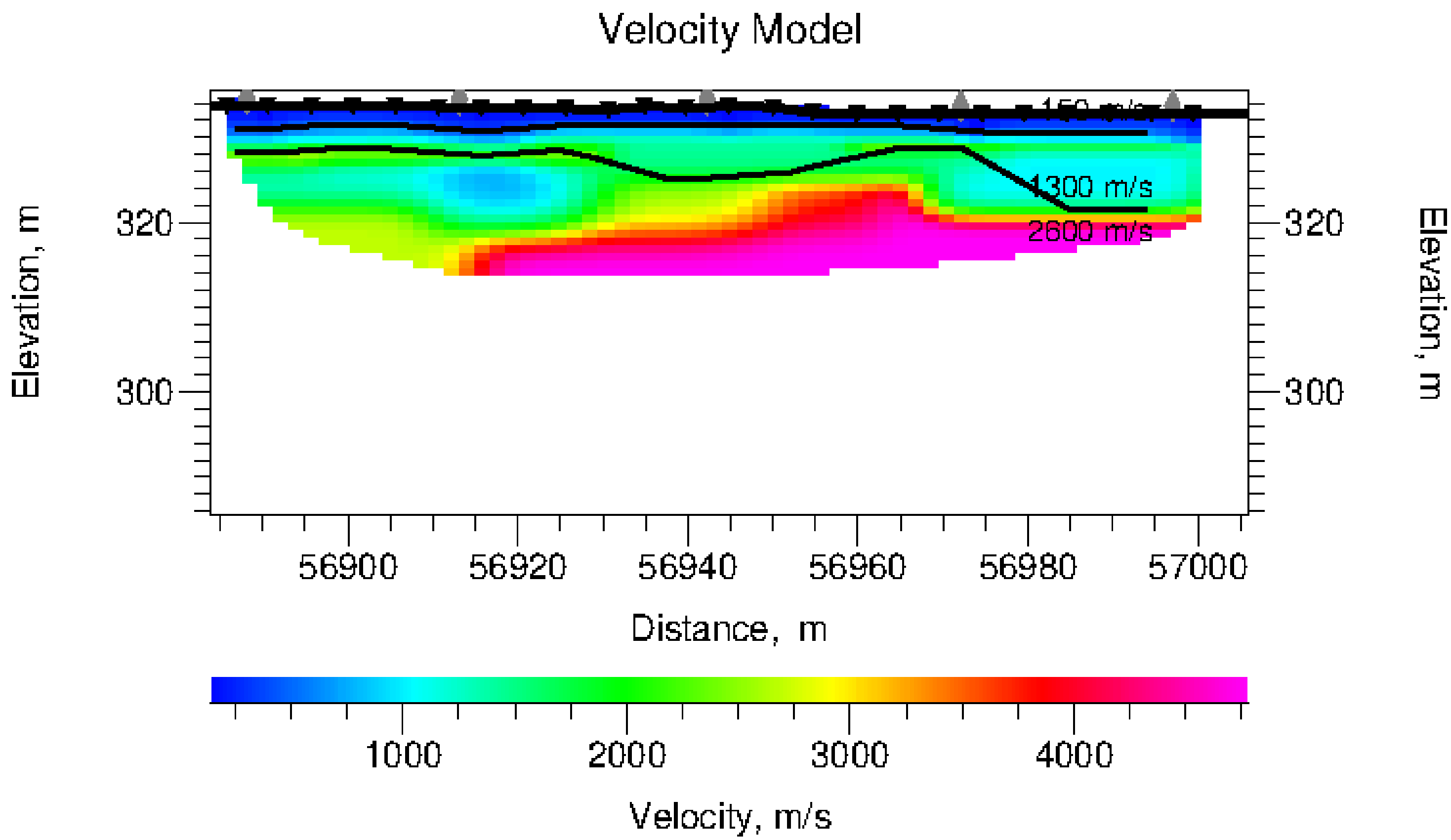
SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 1800m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 5100m/s and is likely to correspond to fresh rock.



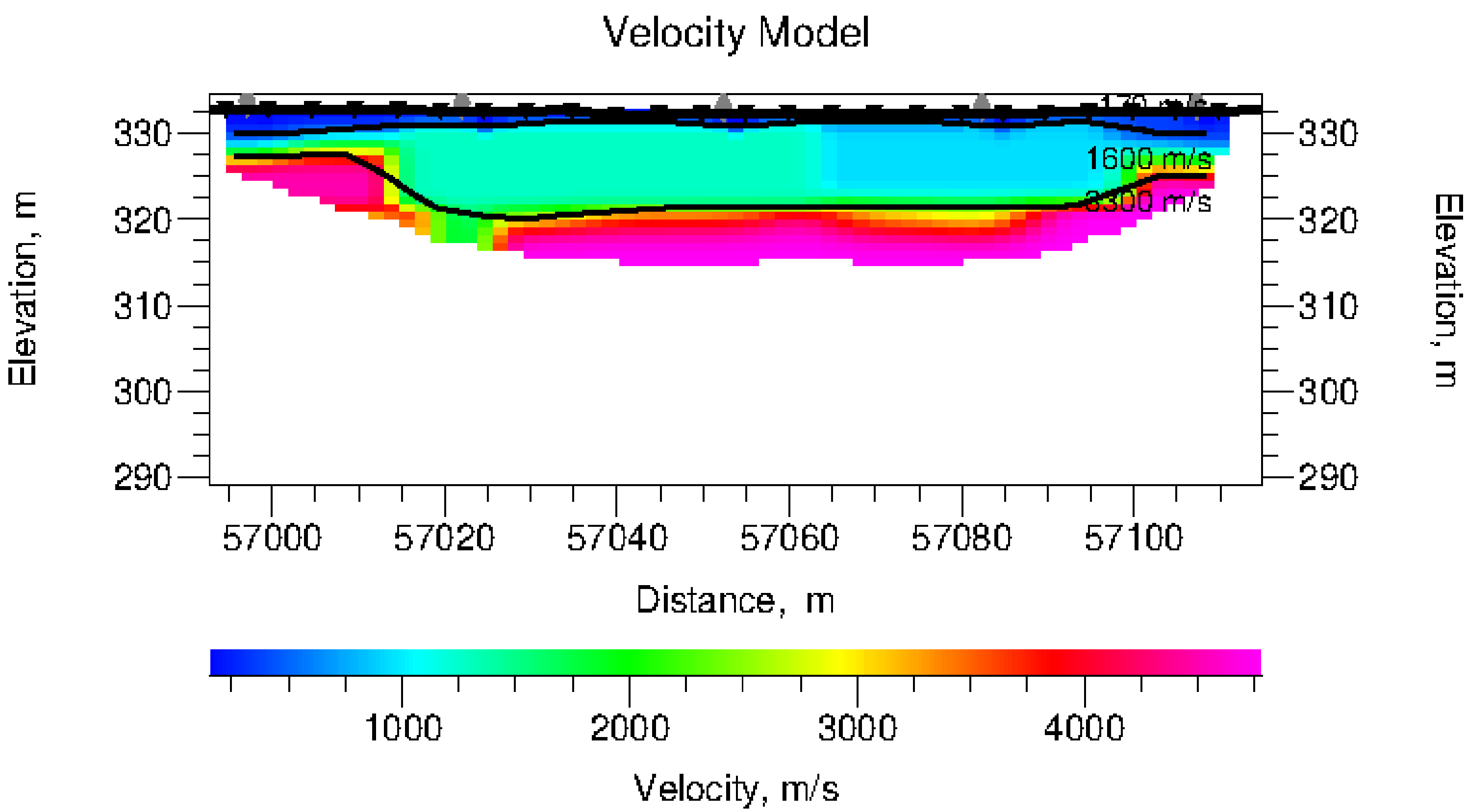
SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 1800m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 4700m/s and is likely to correspond to fresh rock.



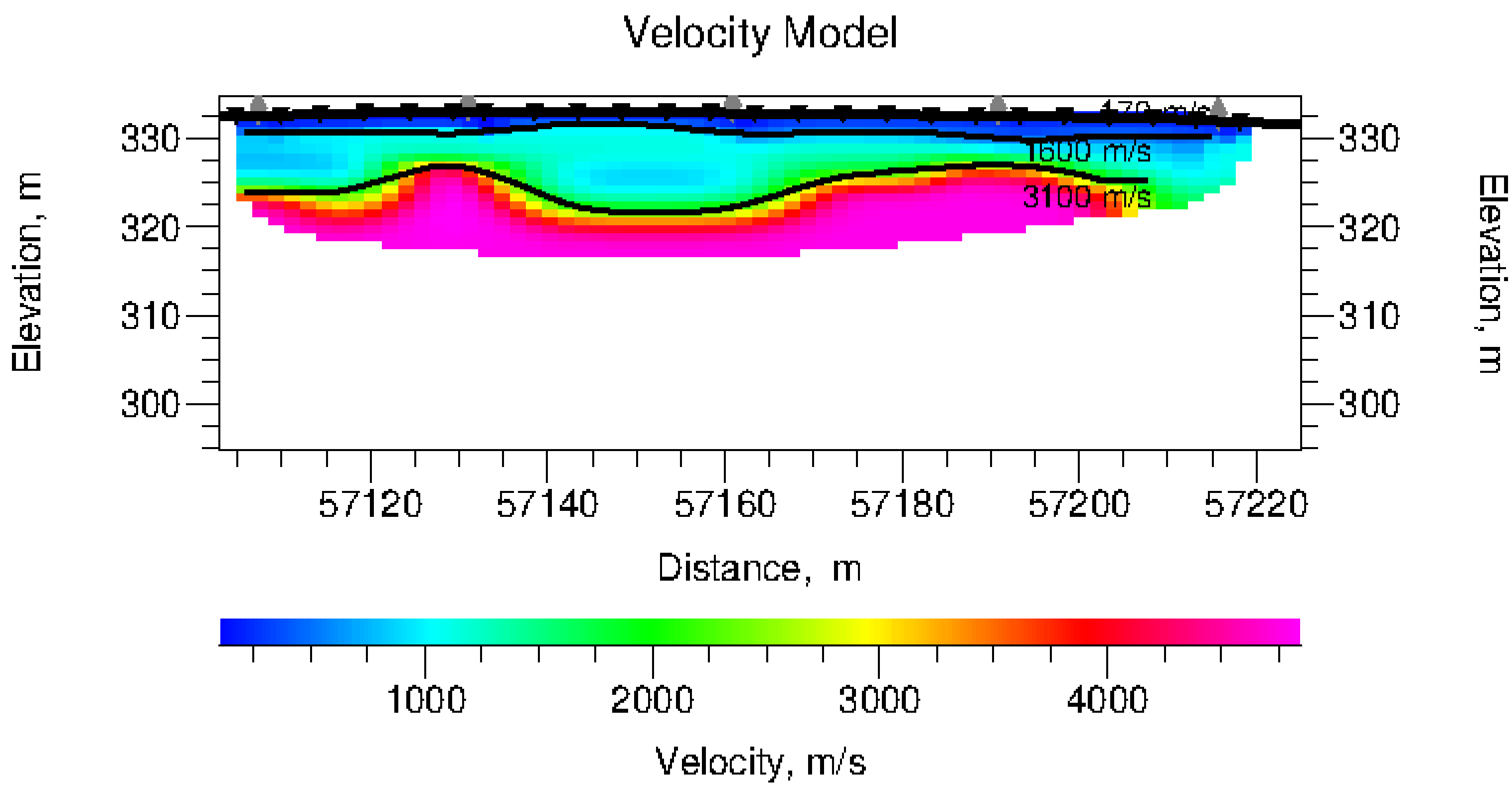
SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 1000m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 2800m/s and is likely to correspond to highly weathered rock.



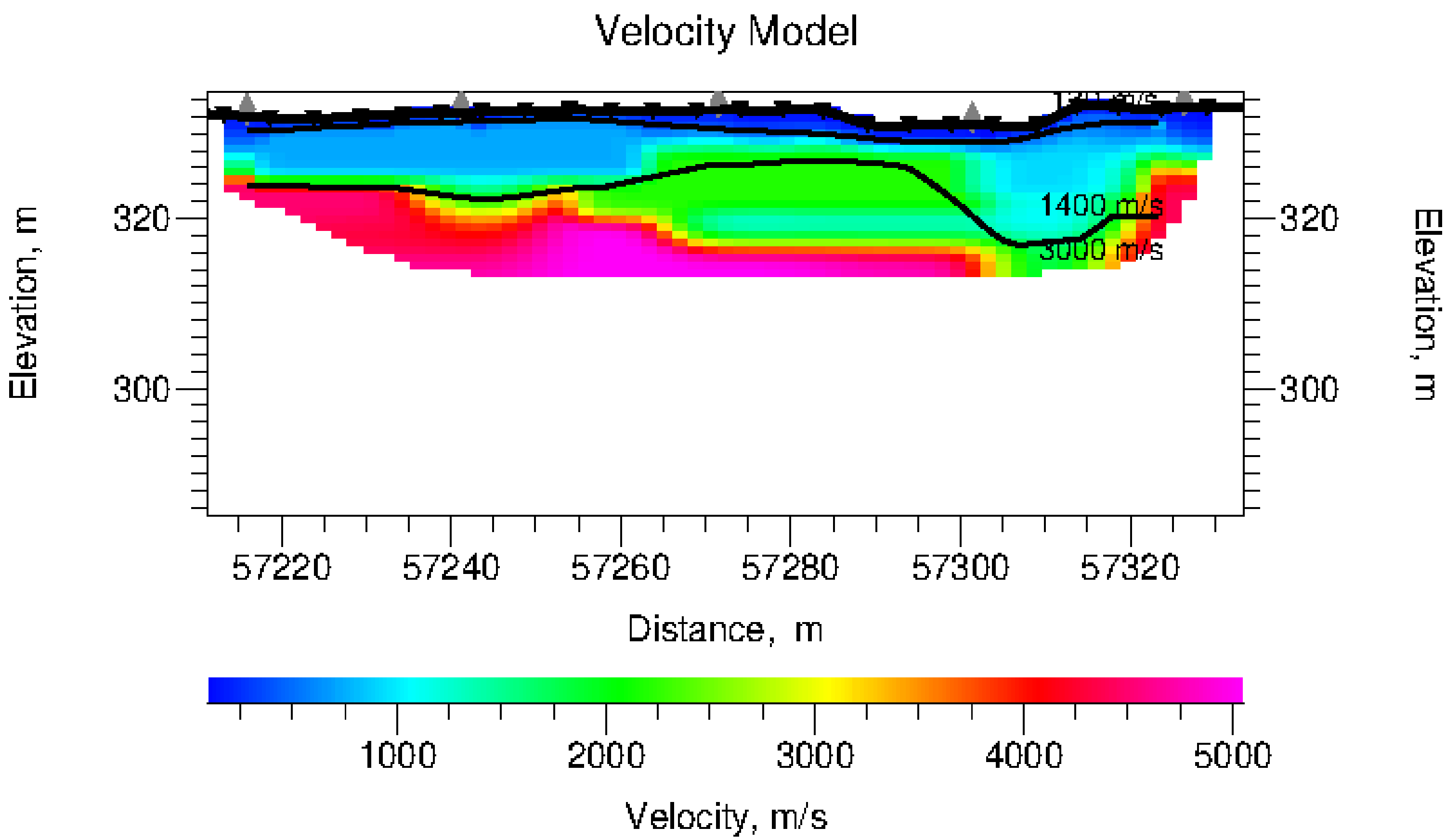
SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 1300m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 2600m/s and is likely to correspond to highly weathered rock.



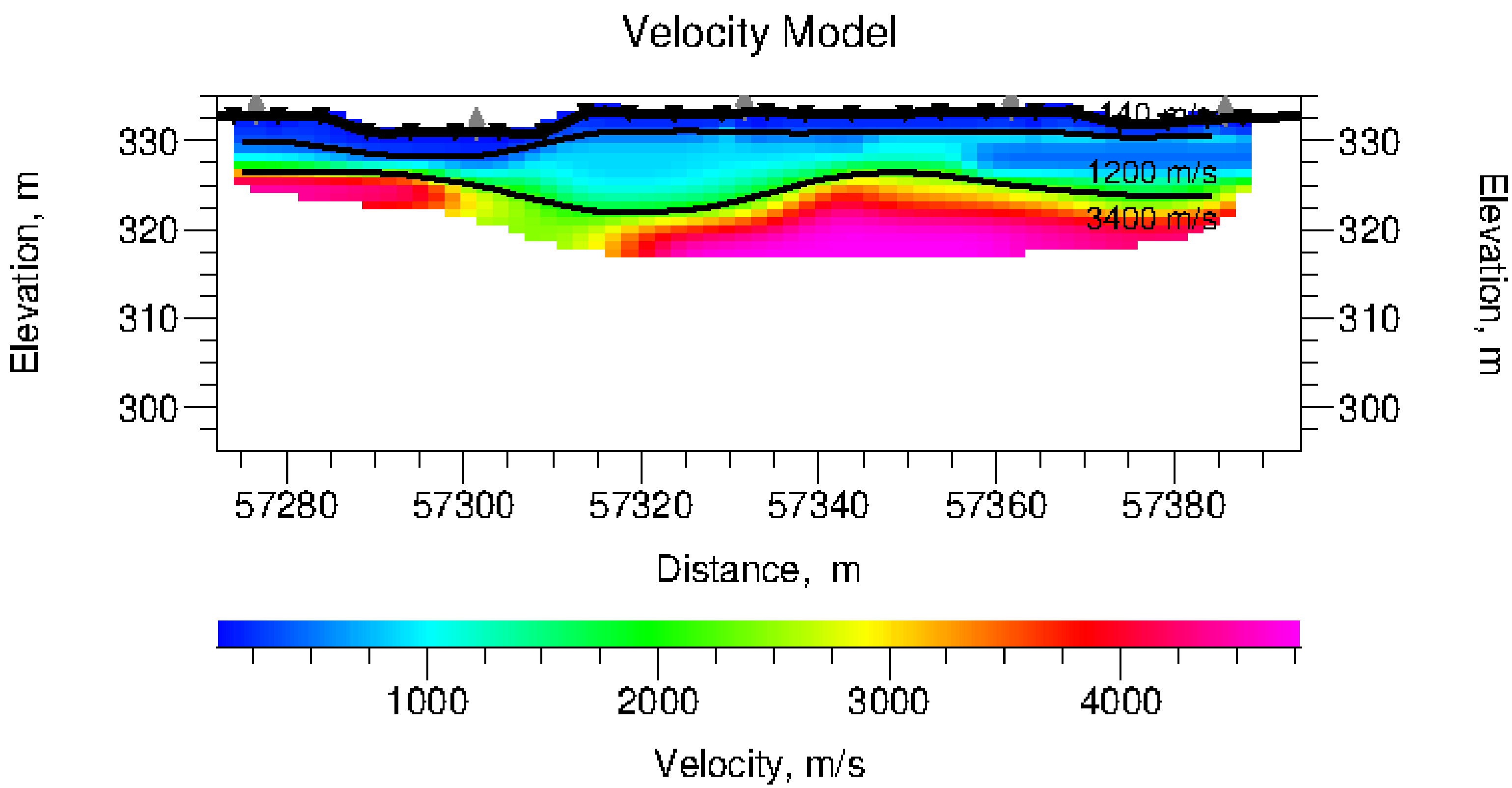
SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 1600m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 3300m/s and is likely to correspond to highly weathered rock.



SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 1600m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 3100m/s and is likely to correspond to highly weathered rock.

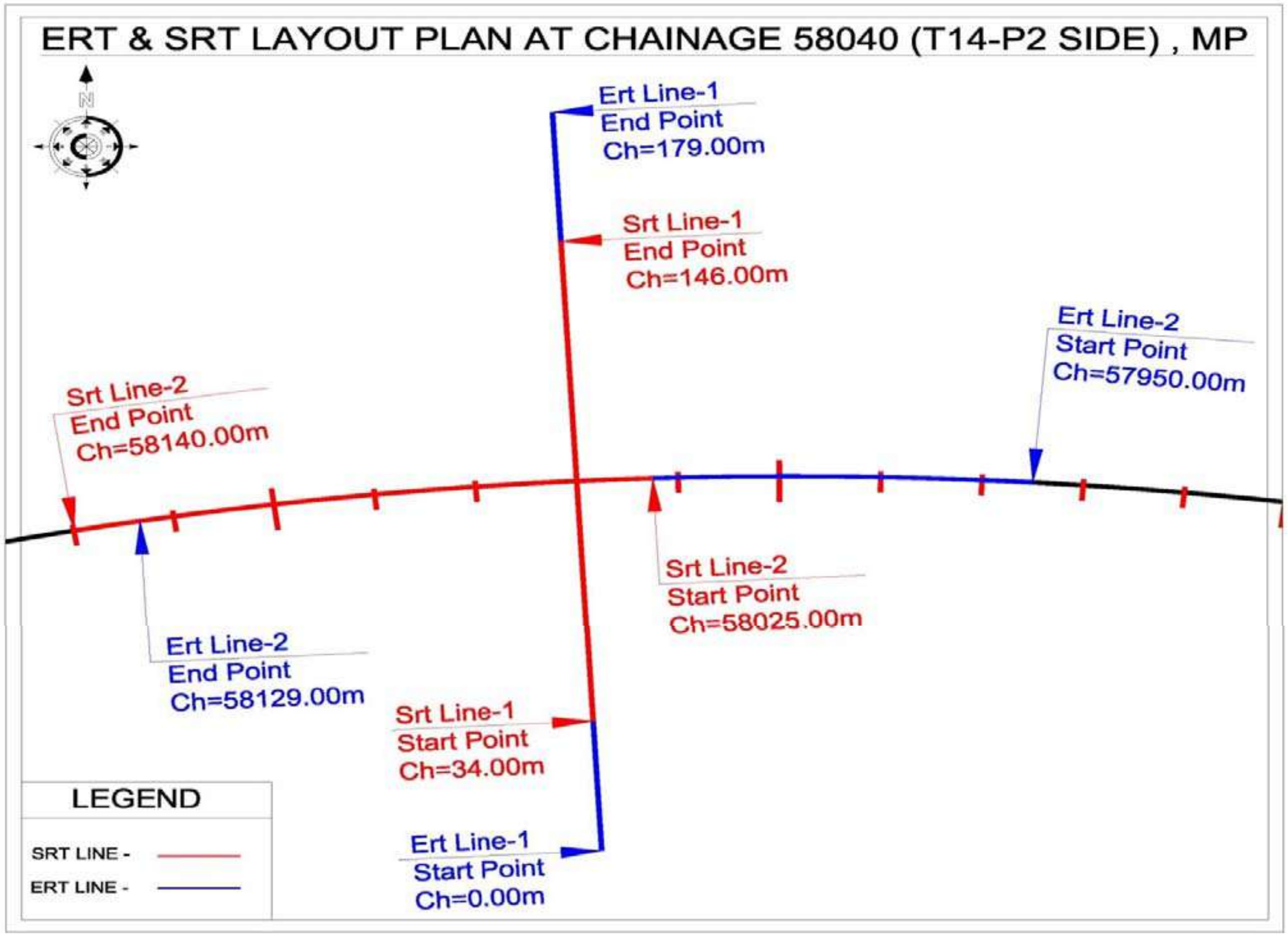


SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 1400m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 3000m/s and is likely to correspond to highly weathered rock.

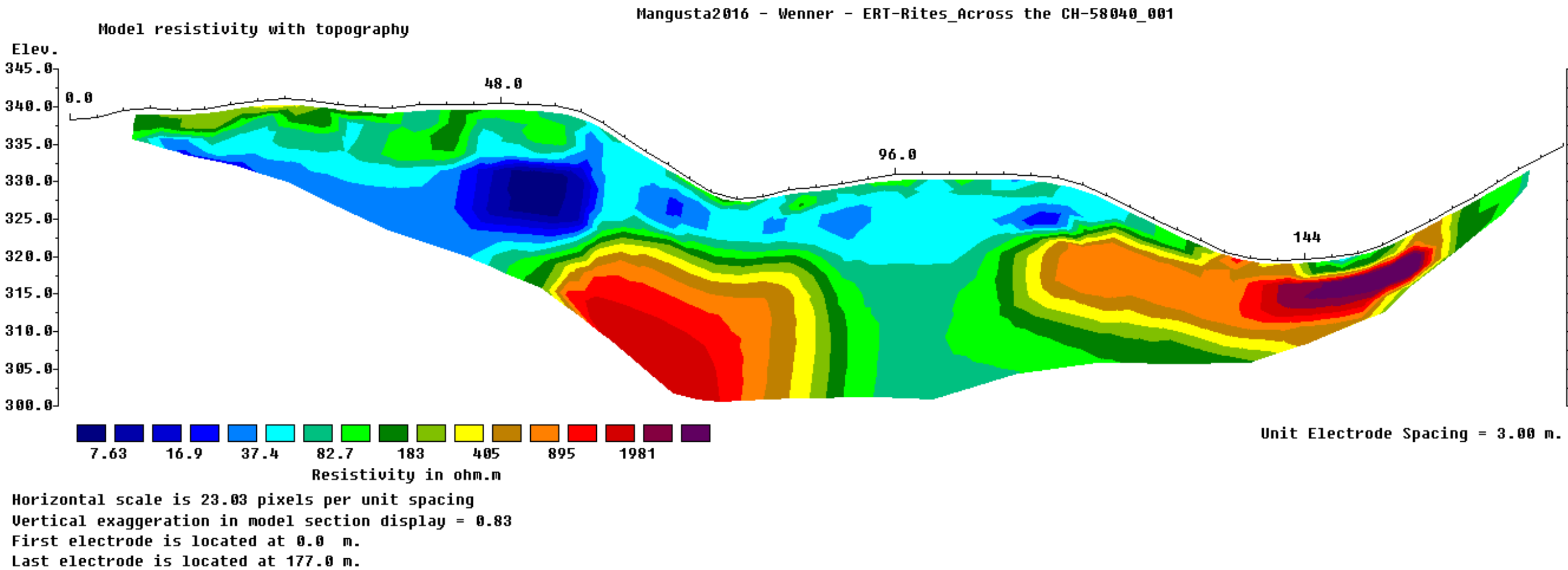


SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 1200m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 3400m/s and is likely to correspond to slightly to highly weathered rock.

ERT & SRT LAYOUT PLAN AT CHAINAGE 58040 (T14-P2 SIDE)

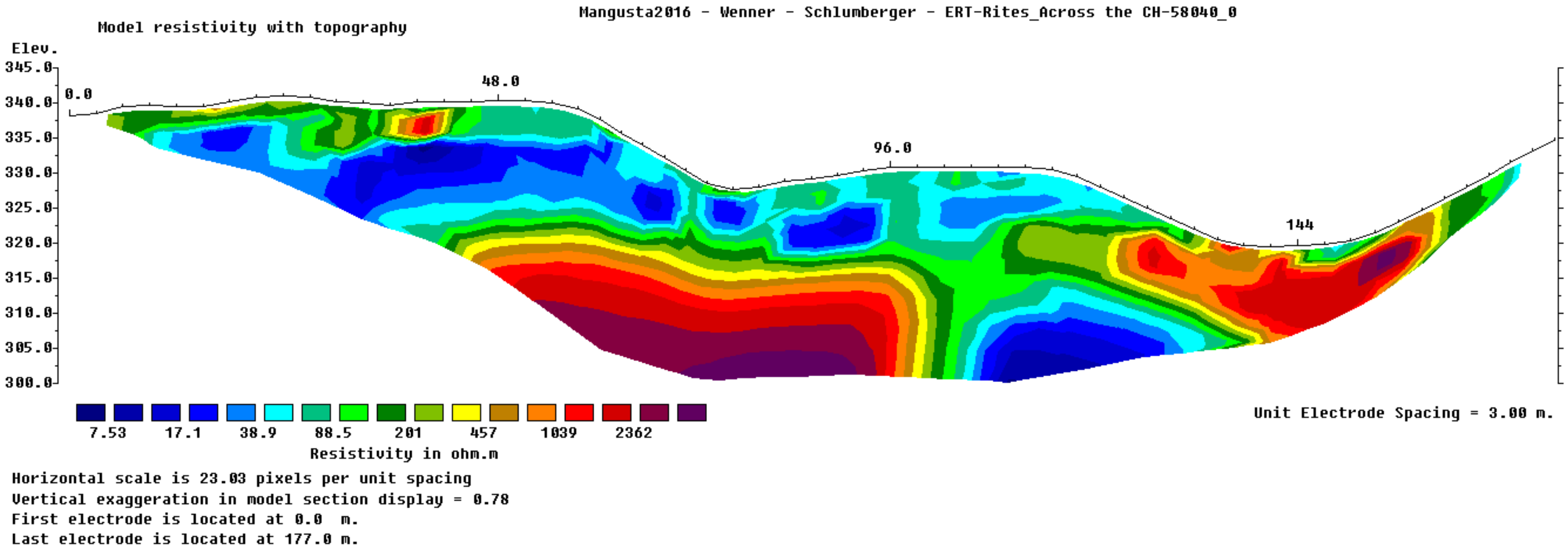


CHAINAGE 58040 (T14-P2 SIDE)ACROSS ERT - W



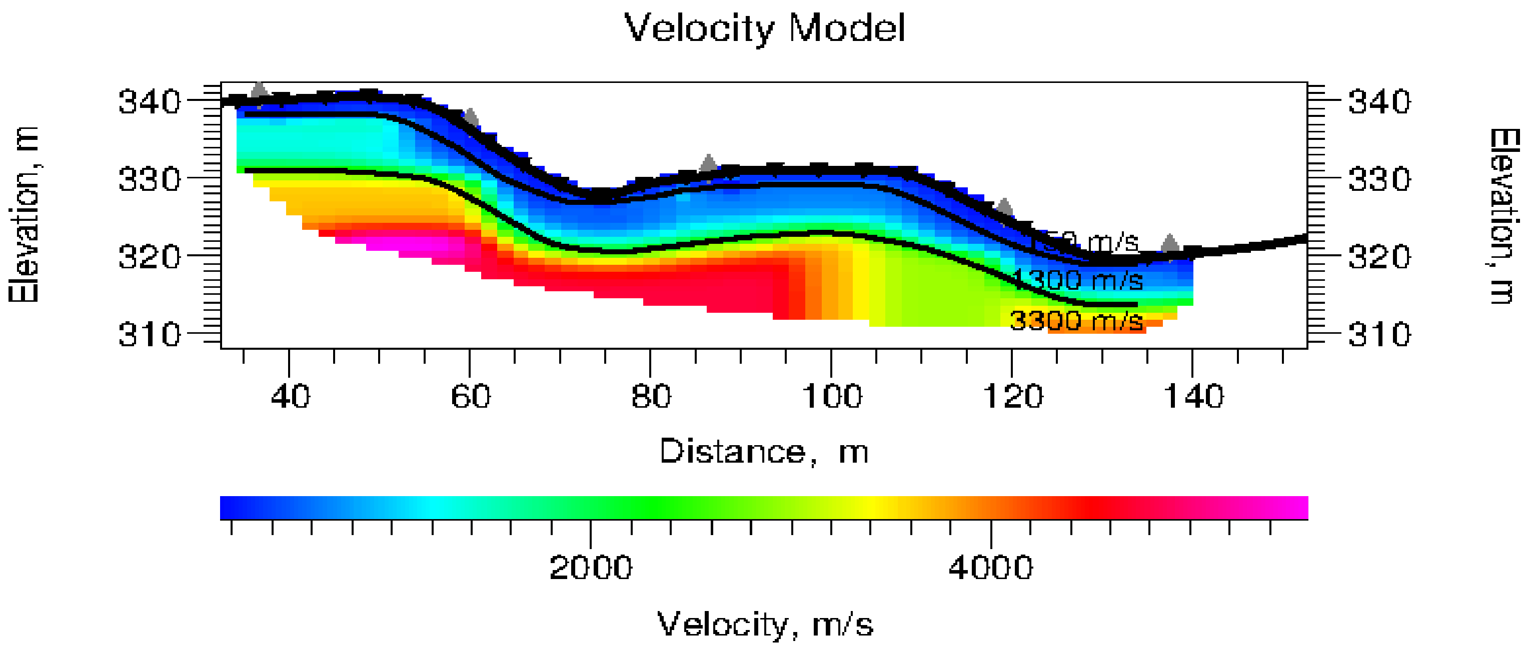
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the left and center-right of the profile.

CHAINAGE 58040 (T14-P2 SIDE)ACROSS ERT - WS



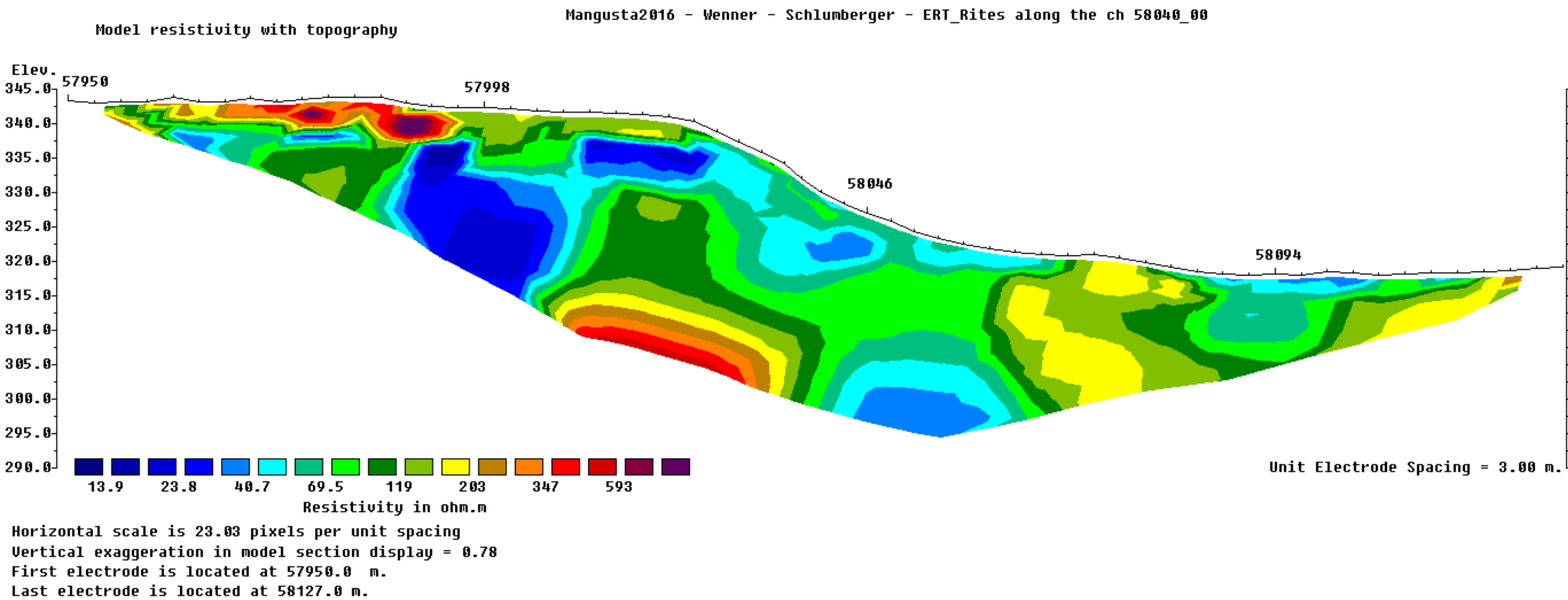
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the left and center-right of the profile.

CHAINAGE 58040 (T14-P2 SIDE)ACROSS SRT



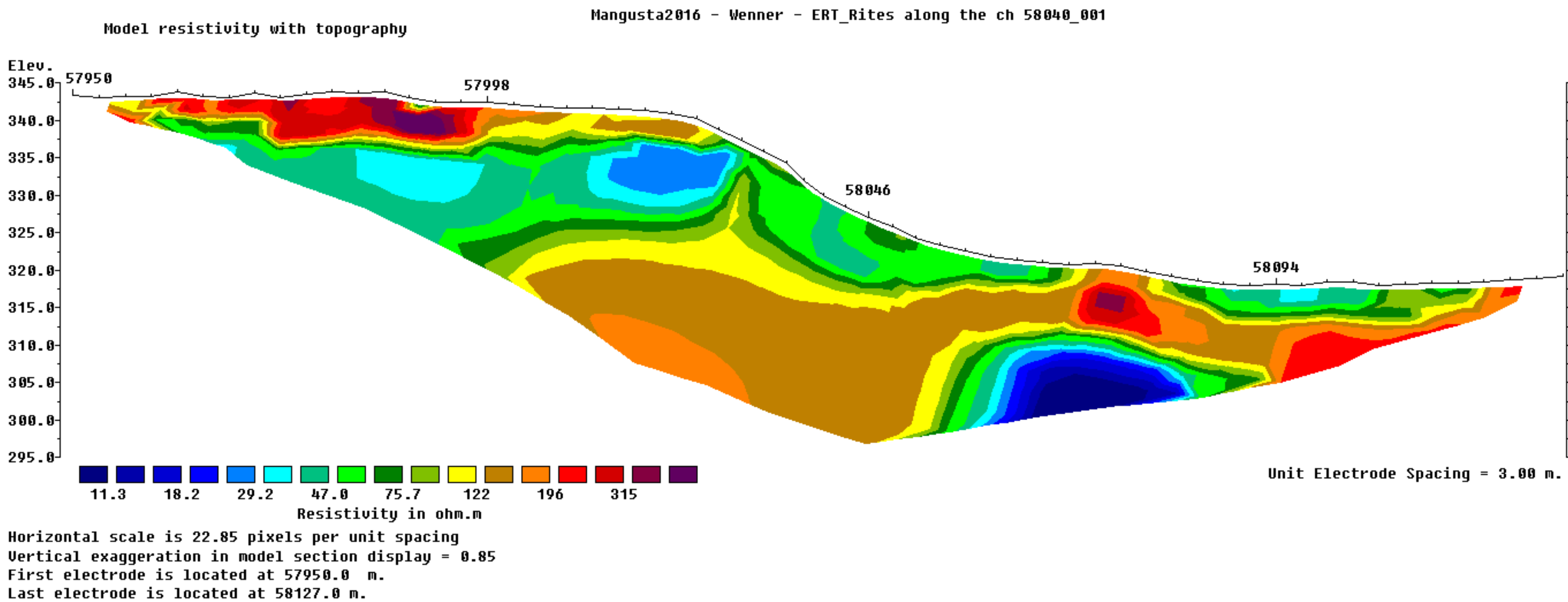
SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 1300m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 3300m/s and is likely to correspond to slightly to highly weathered rock.

CHAINAGE 58040 (T14-P2 SIDE)ALONG ERT - WS



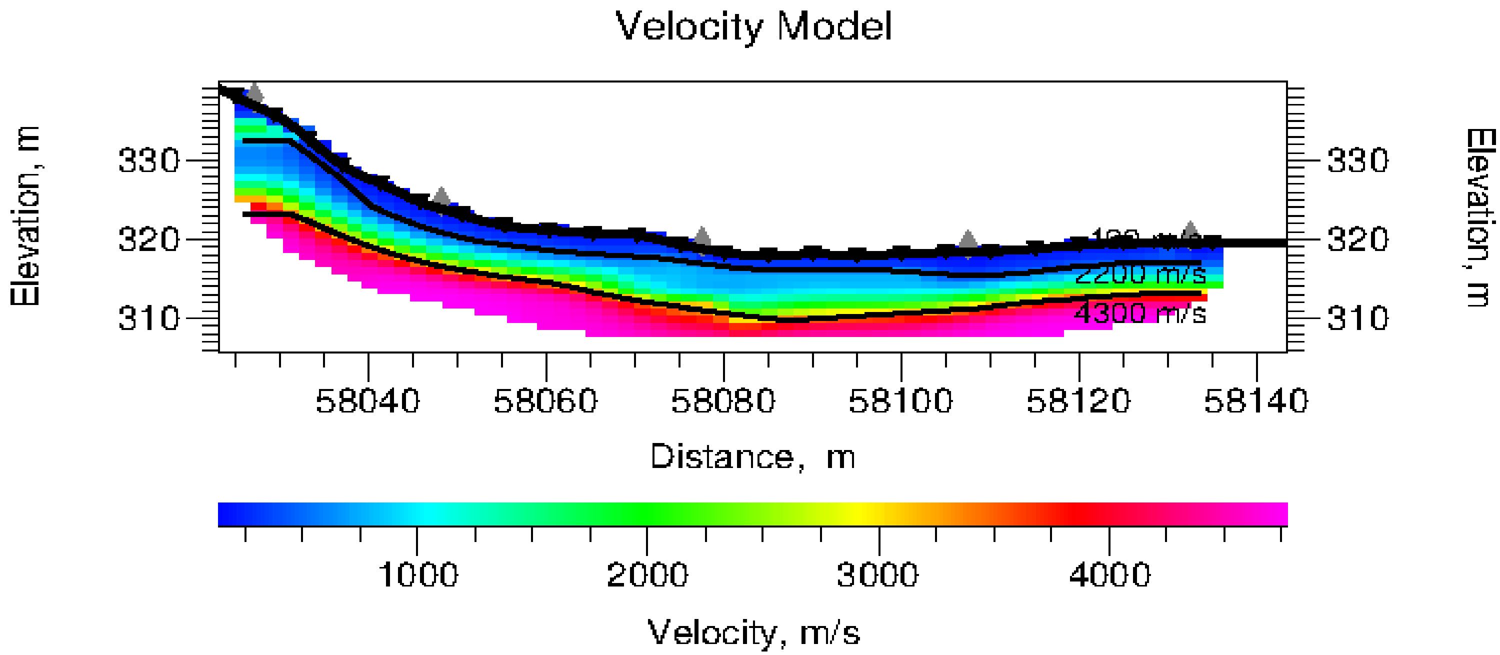
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the left and center-right of the profile.

CHAINAGE 58040 (T14-P2 SIDE)ALONG ERT - W



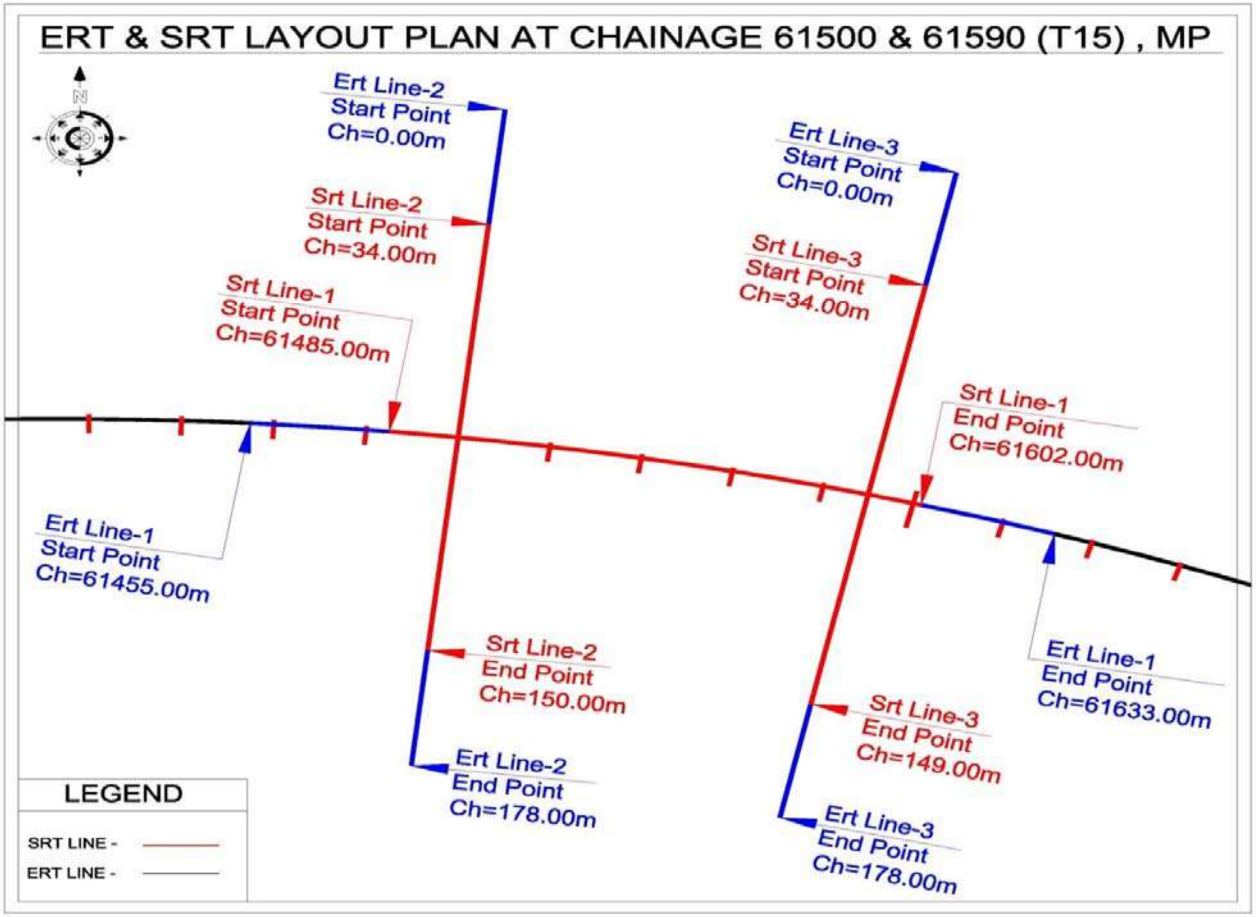
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the left and center-right of the profile.

CHAINAGE 58040 (T14-P2 SIDE)ALONG SRT

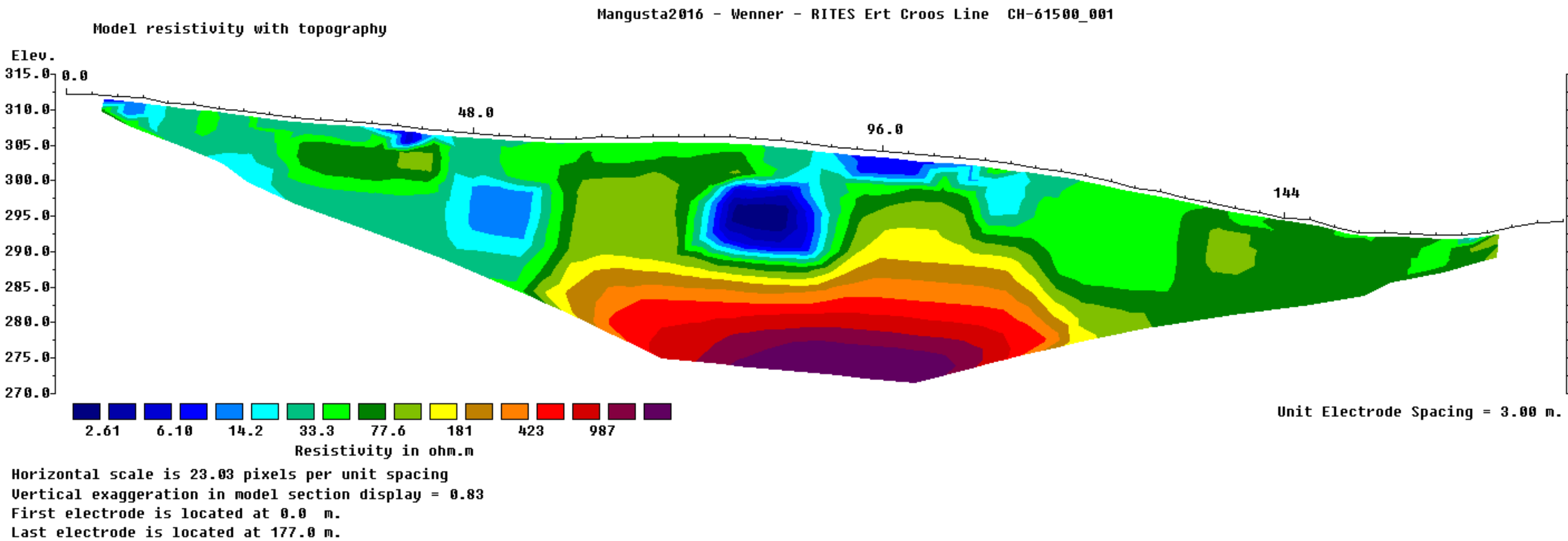


SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 2200m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 4300m/s and is likely to correspond to slightly weathered rock.

ERT & SRT LAYOUT PLAN AT CHAINAGE 61500 & 61590 (T15)

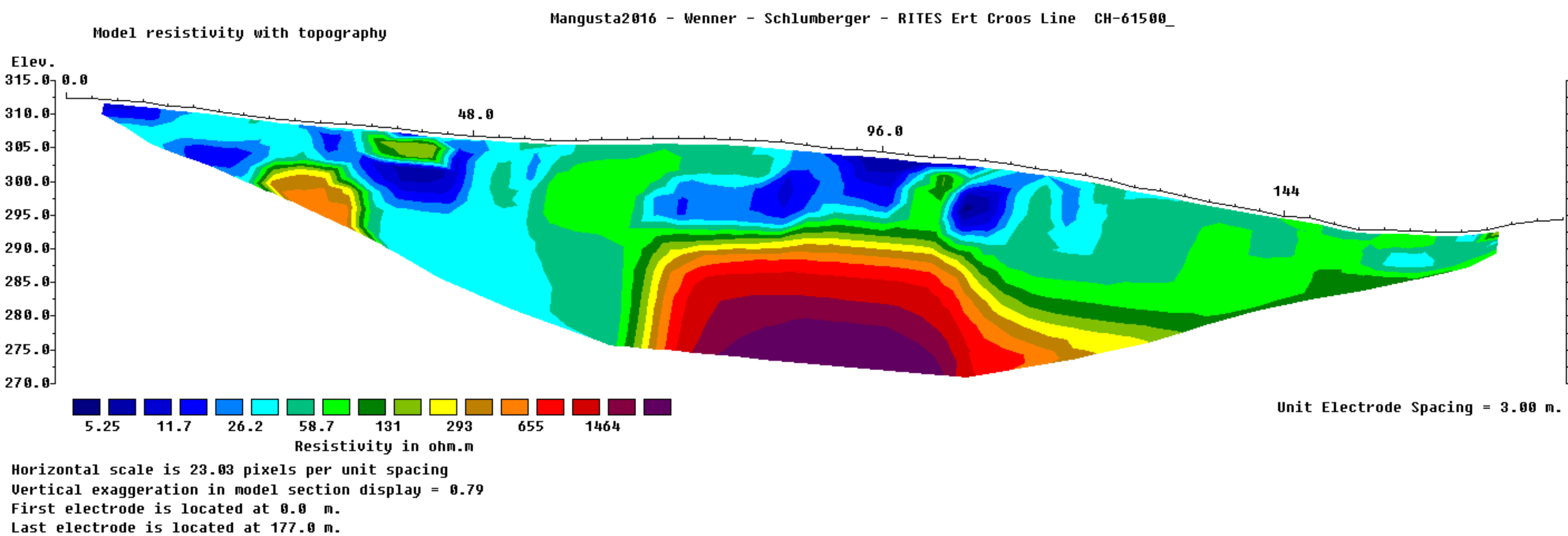


CHAINAGE 61500 ACROSS ERT-W



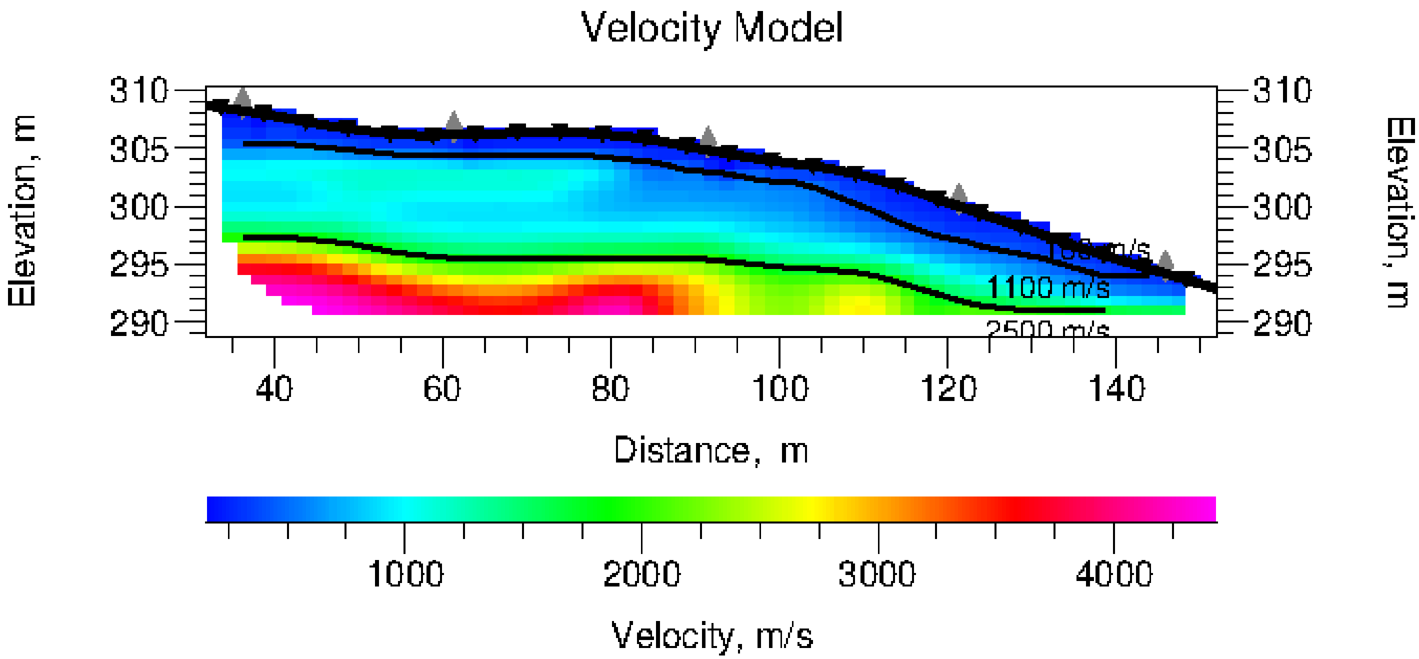
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral and vertical changes in resistivity values and lower values in top layer of the profile.

CHAINAGE 61500 ACROSS ERT-WS



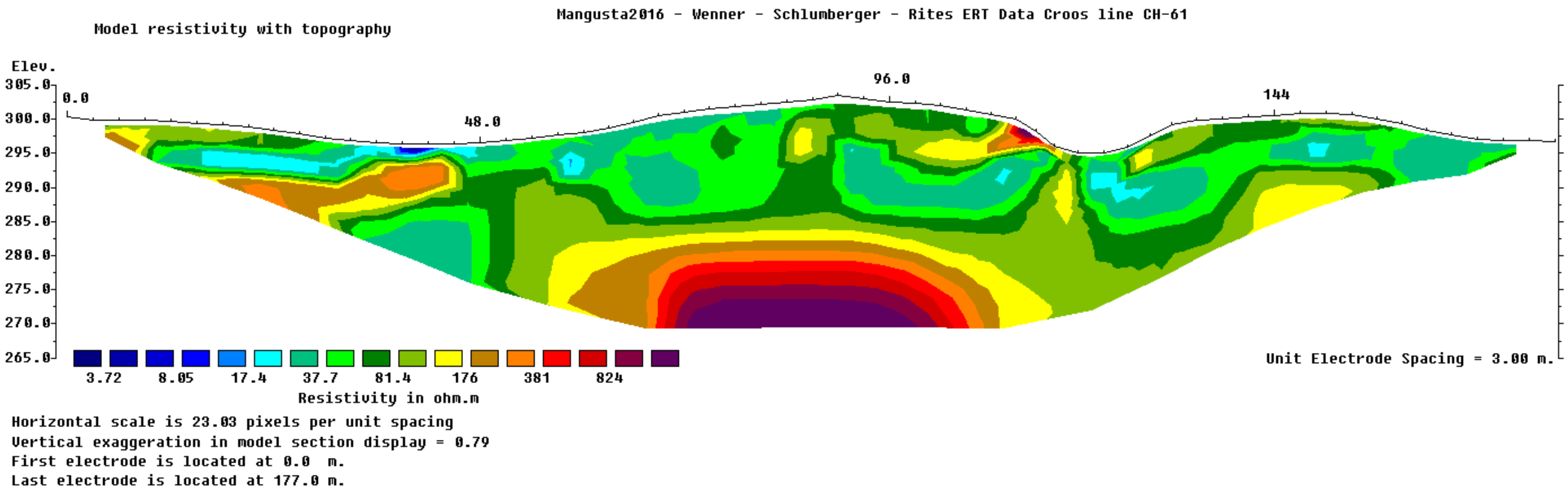
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral and vertical changes in resistivity values and lower values in top layer of the profile.

CHAINAGE 61500 ACROSS SRT



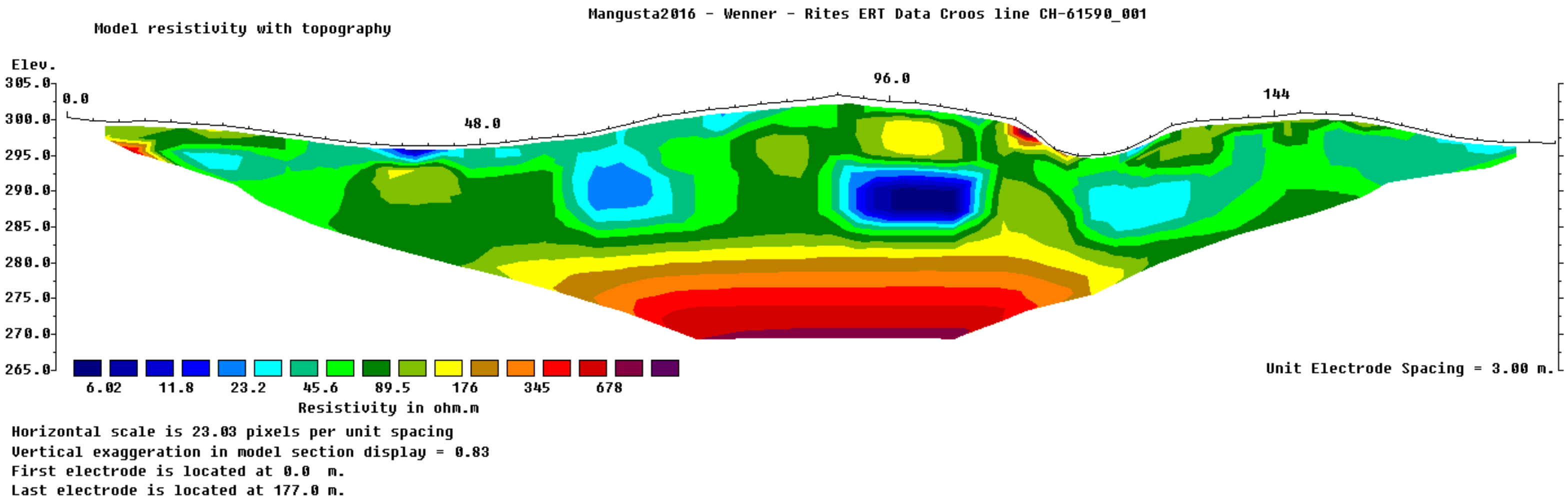
SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 1100m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 12500m/s and is likely to correspond to highly weathered rock.

CHAINAGE 61590 (T15) ACROSS ERT-WS



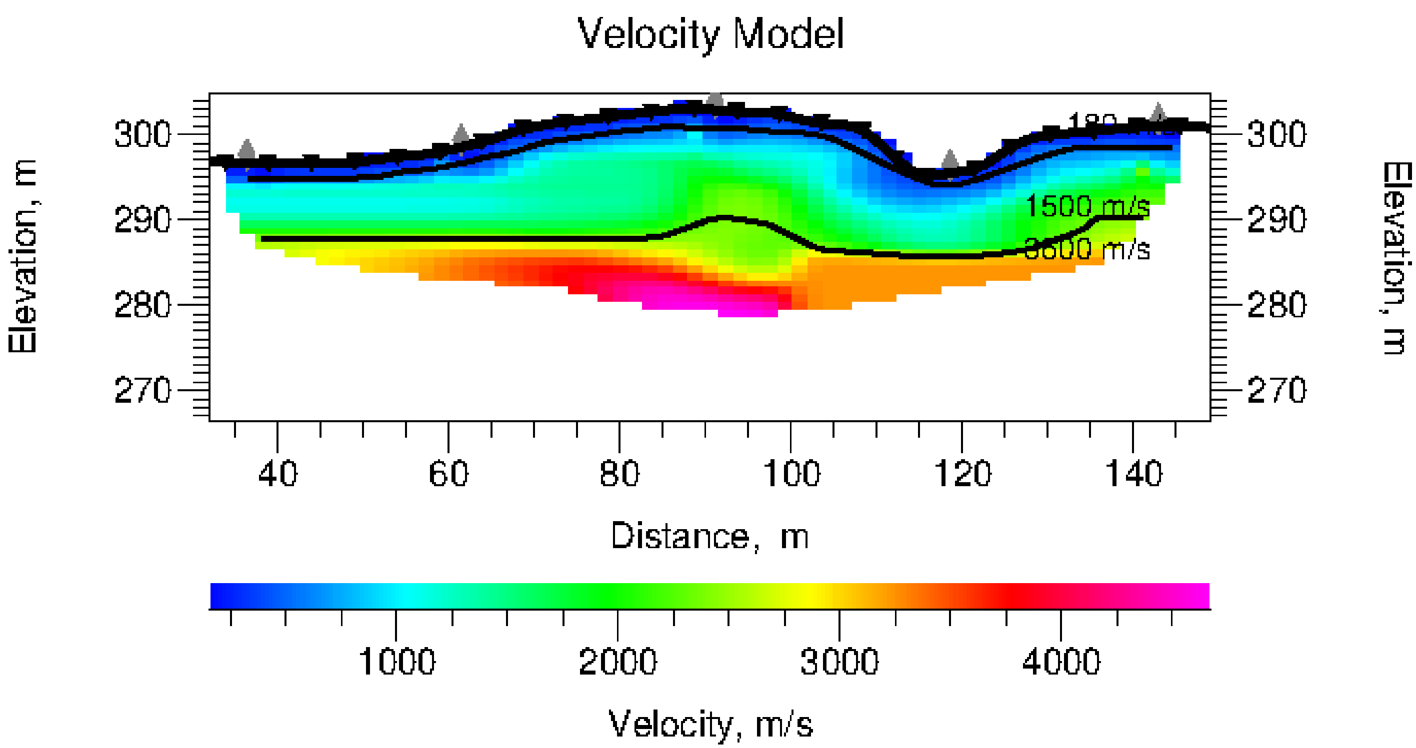
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral and vertical changes in resistivity values and lower values in top layer of the profile.

CHAINAGE 61590 (T15) ACROSS ERT-WS



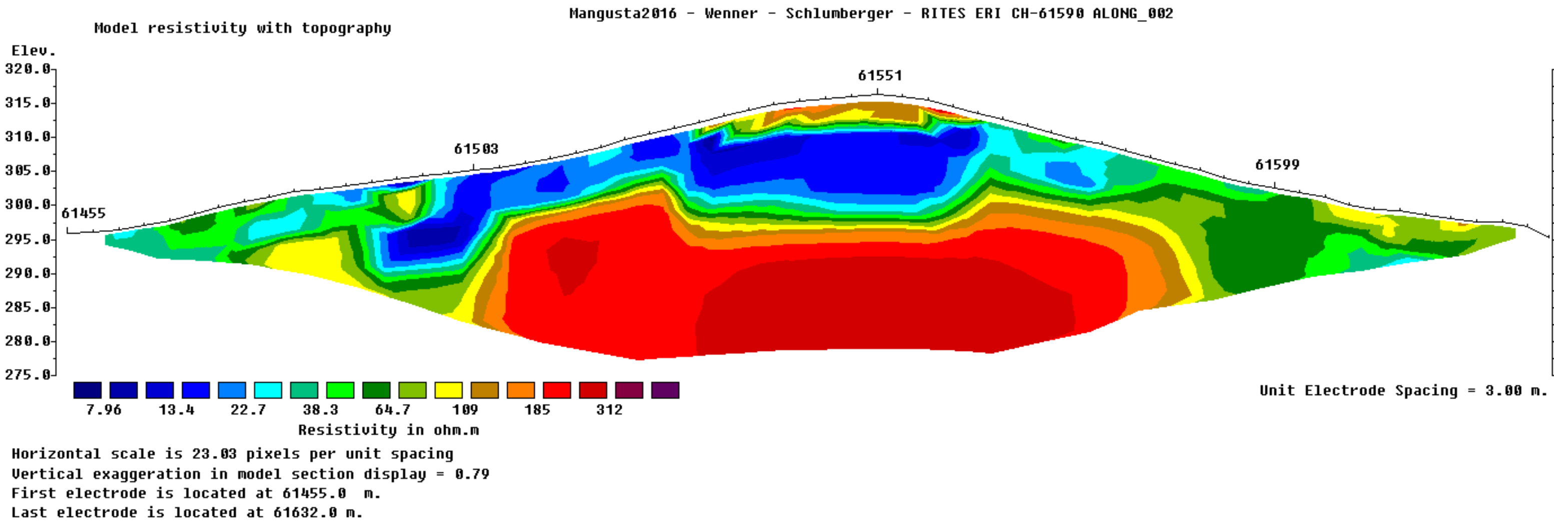
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral and vertical changes in resistivity values and lower values in top layer of the profile.

CHAINAGE 61590 (T15) ACROSS SRT



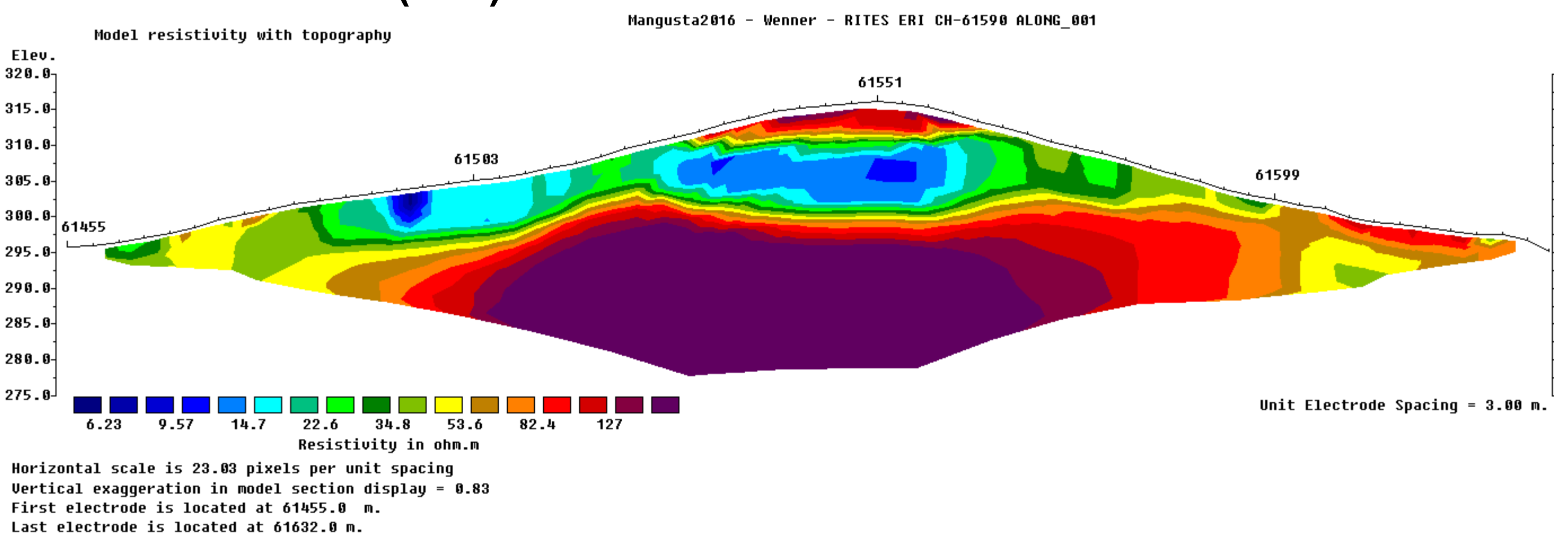
SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 1500m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 3600m/s and is likely to correspond to slightly to highly weathered rock.

CHAINAGE 61590 (T15) ALONG ERT-WS



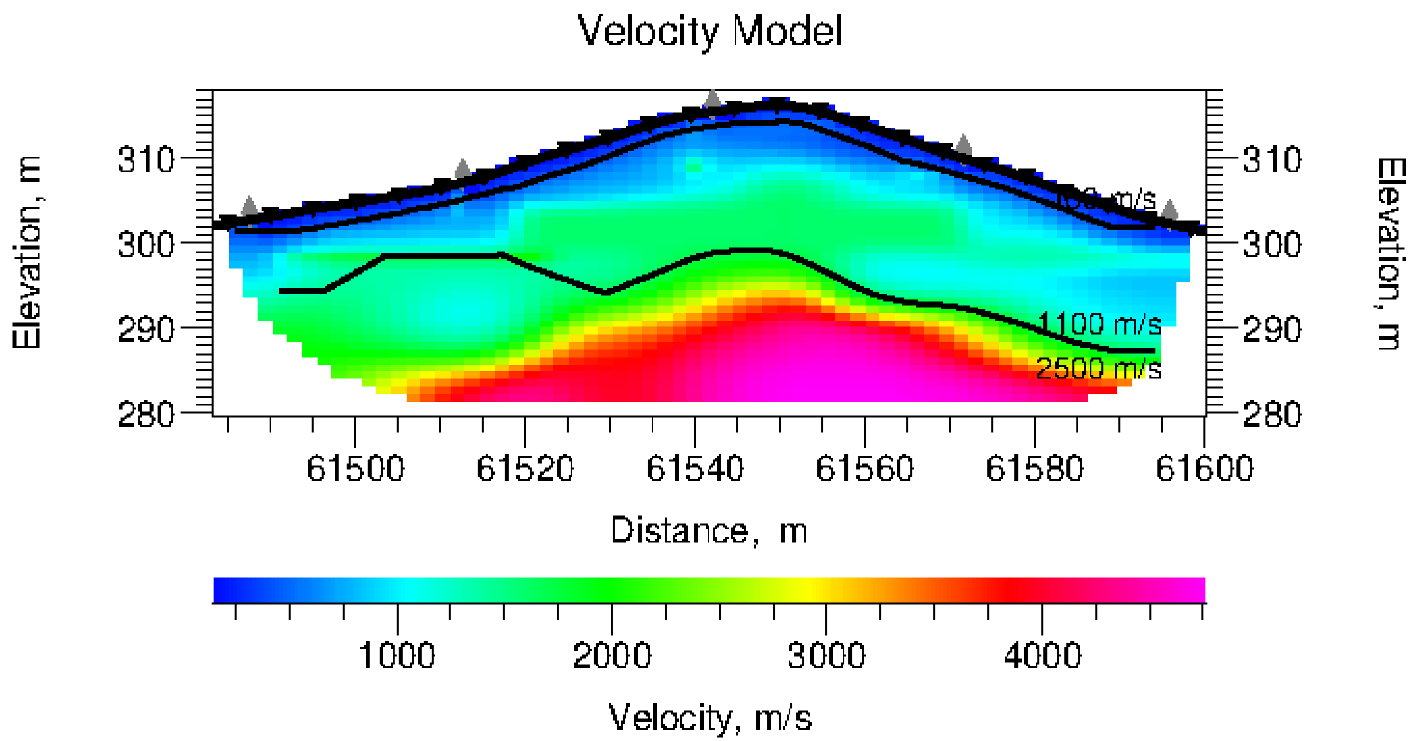
Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral and vertical changes in resistivity values and lower values in top layer of the profile.

CHAINAGE 61590 (T15) ALONG ERT-WS



Interpretation: ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral and vertical changes in resistivity values and lower values in top layer of the profile.

CHAINAGE 61590 (T15) ALONG SRT



SRT Interpretation: Here in this stretch, profile length of 115m (along the ground) with geophone spacing of 05m, three-layer stratigraphy is encountered depicted. The first layer having compressional wave velocity of <200m/s represents top overburden. The second layer has P wave velocity of approximately 1100m/s and is likely to represent more compacted strata and might be completely fragmented/ weathered rock. The third and final layer encountered has velocity of 2500m/s and is likely to correspond to highly weathered rock.

Engineering Properties of rock mass

Based on the seismic velocity, rock mass classification as per Barton's 'Q' values has been attempted for stability of excavation of tunnel. The empirical relations used for calculation of the parameters are referred as under:

(1) Rock Quality $\boldsymbol{Q = 10^{\left(\frac{Vp-3500}{1000}\right)}}$ (Barton's et al. 1993)

(2) RMR = 15 log Q + 50 (Barton's et al. 1995)

(3) Rock mass strength σc= (0.035*Vp -31.5) Linear regression equation by Freyberg, 1972

The rock mass is classified as per both Q-system (Barton et al., 1974) and RMR System (Barton et al., 1995/9). Based on seismic velocity (Vp) and "Q" value of different layers, an overall appraisal of the rock mass strength (σc), RMR, have been assessed and placed. The following chart has been used to depict the seismic velocities with Q value for support recommendations in further chapters.

Vp in m/sec	1500	2500	3500	4500	5500	6500
Q-Value	0.01	0.1	1.0	10.0	100.0	1000.0

Figure 115 Vp vs Q Value Chart

3 Alignment Details

The provided tunnel alignment in by RITES is tabulated as below:

Table 1 Proposed alignment

S.No.	Parameter	T-9	T-9A	T-10	T-11	T-12	T-12A	T-13	T-14
1	NATM Tunnel length (m)	1470	250	400	810	1280	140	1600	2150
2	Start chainage (km)	km 34+140	km 36+290	km 36+820	km 37+380	km 38+510	km 40+540	km 42+800	km 55+840
3	End Chainage (km)	km 35+610	km 36+540	km 37+220	km 38+190	km 39+790	km 40+680	km 44+400	km 57+990
4	Straight/ Curved tunnel alignment	Curved	Straight	Curved	Curved	Curved	Curved	Curved	Curved
5	Maximum overburden (from FL) (m)	29	29	33	72	88	31	167	41
6	Maximum gradient	Fall 1in150	Fall 1in150	Fall 1in175	Fall 1in175	Fall 1in175	Fall 1in200	Fall 1in150	Fall 1in175

The details of the proposed tunnel alignment with its geometric properties are as summarized table below-

Table 2 Geometric details of tunnels alignment

S.No.	Tunnel	Curve radius	Points on curve	Chainage
1	T-9	875 m (Curve no.20)	TPTC-1	km 34+387.53
			TPCC-1	km 34+477.53
			TPCC-2	km 35+000.25
			TPTC-2	km 35+090.28
2	T-10 T-11	875 m (Curve no.21)	TPTC-1	km 37+005.08
			TPCC-1	km 37+095.08
			TPCC-2	km 38+015.59
			TPTC-2	km 38+105.59
3	T-12	777.78 m (Curve no.22)	TPTC-1	km 38+432.68
			TPCC-1	km 38+542.68
			TPCC-2	km 39+673.56
			TPTC-2	km 39+783.56
4	T-12A & T-13	777.78 m (Curve no.23)	TPTC-1	km 41+665.84
			TPCC-1	km 41+775.84
			TPCC-2	km 42+958.88
			TPTC-2	km 43+068.86
5	T-13	777.78 m (Curve no.24)	TPTC-1	km 43+475.73
			TPCC-1	km 43+585.73
6	T-14	777.78 m (Curve no.31)	TPTC-1	km 55+040.71
			TPCC-1	km 55+150.74
			TPCC-2	km 56+155.42
			TPTC-2	km 56+265.42
7		777.78 m (Curve no.32)	TPTC-1	km 57+528.20
			TPCC-1	km 57+638.20
			TPCC-2	km 58+058.21
			TPTC-2	km 58+168.21

4 <u>Theory on Primary lining</u>

4.1 Primary Support

The purpose of the primary support is to stabilize the underground opening until the final lining is installed. In many cases it may become necessary to apply the support system in combination with auxiliary constructional measures. The most common elements for the primary support are:

a) Rock bolts: Rock reinforcement in tunnels (of which rock bolt is one of the types) is used for many purposes. There are many types of rock bolts, with many of them being patented products, generally made of steel (mostly reinforcement bars of suitable diameter).

A borehole of required diameter is drilled in the rock mass and the bolt is inserted in the borehole. The bolt is anchored near the tip using suitable mechanism, then it is stressed, and the bore hole mouth is covered by using a face plate and face nut. Afterwards, grouting is done (in most of the cases) to fill up the annular space between the bolt and the walls of the borehole. In case bore hole does not remain stable until withdrawal of drill rod and insertion of bolt, Self-Drilling Rock bolts (SDR) or Self-Drilling Anchors (SDA) are used, wherein the drill bit is located at the end of bolt and borehole is drilled using the bolt and drill bit. In such a system, the drill bit is not re-used, and one drill bit gets scarified in each borehole. SDAs or SDRs are costly as compared to normal rock bolts, but their use is necessary in case of weak ground tunnelling. When the required length of rock bolts becomes excessive (say more than 10m or so), rock anchors (which are made of woven high tensile steel ropes) are used in pace of steel bolts.

Rock bolts serve many purposes in the tunnels. Major purpose of rock bolts is to support individual rock block(s), which may become loose due to creation of cavity and may have eventually fallen in figure below.

b) Shotcrete: Shotcrete is the process in which cement, sand and fine aggregate concrete conveyed through a hose and pneumatically projected at high velocity onto a surface, as a construction technique.

Dry Mix Shotcrete: Dry shotcrete components – which may be slightly pre-dampened to reduce dust – are fed into a hopper with continuous agitation.

Compressed air is introduced through a rotating barrel or feed bowl to convey the materials in a continuous stream through the delivery hose. Water is added to the mix at the nozzle. Gunite, a proprietary name for dry- sprayed mortar used in the early 1900s, has fallen into disuse in favour of the more general term shotcrete.

Wet Mix Shotcrete

In this case, shotcrete components and water are mixed (usually in a truck-mounted mixer) before delivery into a positive displacement pumping unit, which then delivers the mix hydraulically to the nozzle where air is added to project the material onto the rock surface. The final product of either the dry or wet shotcrete process is very similar. The dry mix system tends to be more widely used in tunnelling because of inaccessibility for large transit mix trucks and because it generally uses smaller and more compact equipment. This can be moved around relatively easily in an underground environment. The wet mix system is ideal for high production applications in tunnelling and civil engineering where a deep shaft or long tunnel is being driven and where access allows the application equipment and delivery trucks to operate on a relatively continuous basis. Decisions to use dry or wet mix shotcrete processes are usually made on a site-by-site basis.

c) **Steel ribs and lattice girder:** They are fabricated at site, to the required cross section of tunnel, by welding of reinforcement bars. These types of supports are relatively light weight (hence economical), flexible and easy to handle. They are normally installed with shotcrete (Fig. below). Use of such supports is very common nowadays and their flexibility is an added advantage, as will be discussed subsequently in “Rock Structure Interaction”.

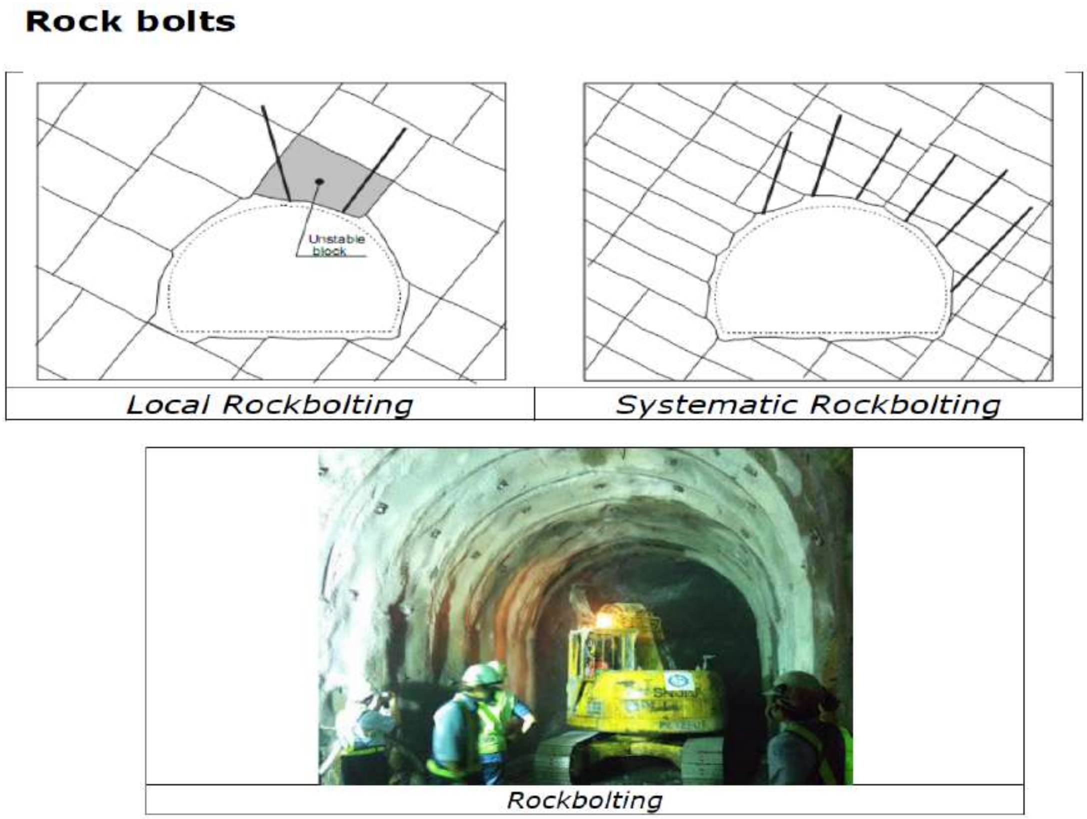


Figure 116 Rock bolting

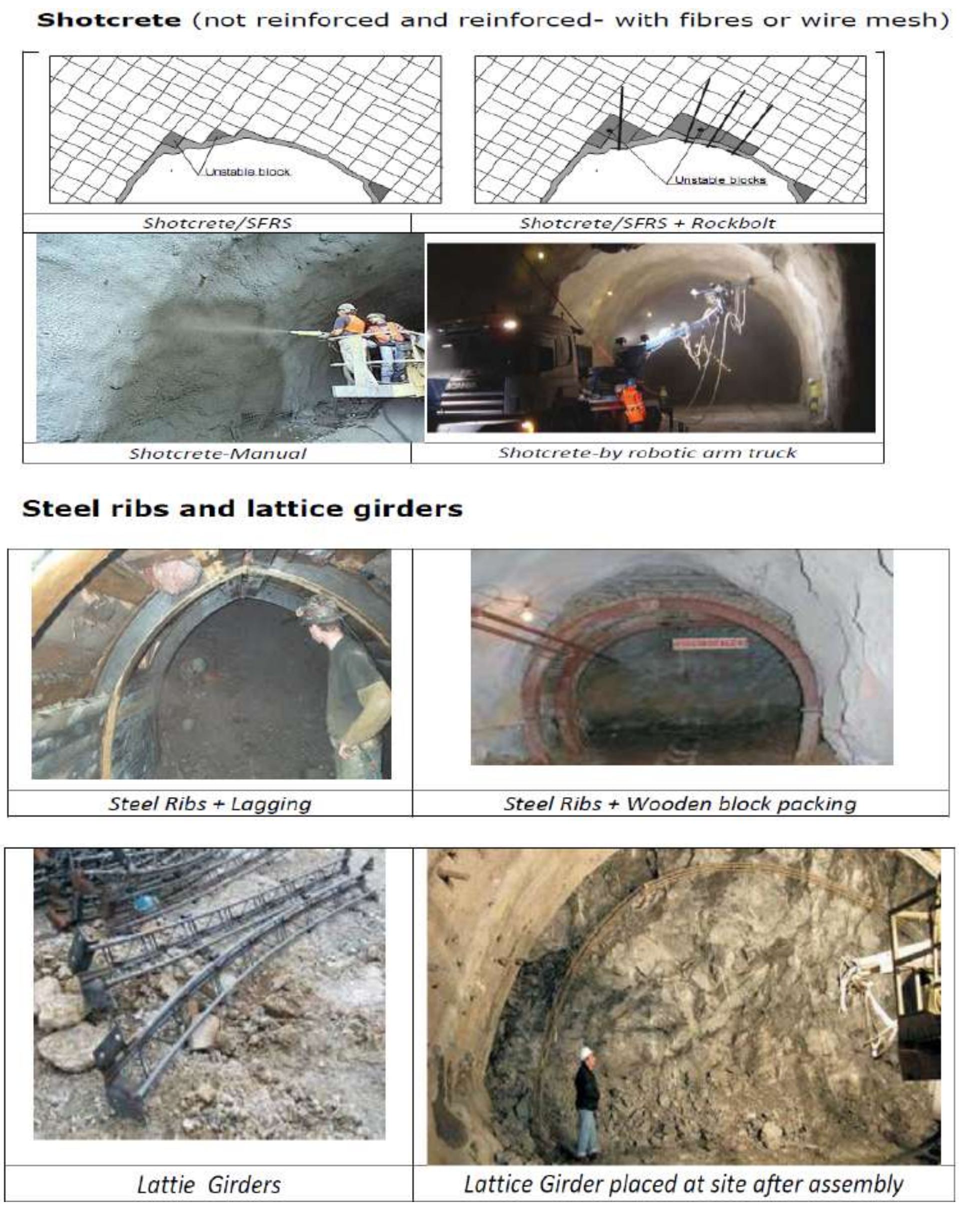


Figure 117 Shotcrete, steel ribs Lattice Girder

This report covers analysis and Preliminary design of tunnel T-2 to T-8 in Ratlam-Khandwa section. Analysis of excavation and support for tunnel has been carried out for different ground type which are anticipated to be encountered based on Q classification.

5 References

I. Austrian Society for Geomechanics: Guideline for the Geotechnical Design of Underground Structures with Conventional Excavation, 2010

II. Practical Rock Engineering by Dr. Evert Hoek, 2004

III. Austrian Society for Geomechanics: Guideline for the Geotechnical Design of Underground Structures with Conventional Excavation.

IV. Austrian Concrete Society Publications, Guideline Sprayed Concrete, 2013.

6 <u>Geotechnical Design parameters</u>

Geological survey and mapping of the project area indicate that the tunnels are to be excavated in Basaltic rock comprising majorly Jointed strata. The discontinuities intersecting the rock mass are related to low tectonic history and mechanical properties of individual rock types. On the scale of tunnel profile, the occurrence and frequency of discontinuity sets is variable.

The representative rock mass conditions/ ground types were identified in terms of Geological Strength Index (GSI) values which have been directly taken from the aid of standard chart applicable for the jointed rock mass by P. Marinos and E. Hoek (2000).

Various ground types are classified in rock grades viz. Grade I, Grade II, Grade III, Graded IV and Grade V for evaluating the rock mass parameters, based on observed rock mass conditions.

For each Ground type, the referenced GSI value has also been categorized into a high and low value to account for the minor reduction in quality of joint conditions to differentiate between the weathering conditions. The range of intact rock strength (σci), GSI, intact modulus (Ei) and corresponding rock mass modulus (Erm) values are as per GIR report of tunnels (submitted separately).

Tunnel is divided into sections based on the observed rock quality. The rock mass properties for each section are further assessed for the appropriate rock mass overburden observed in those sections.

It is further observed that there is persistent ground water present across the tunnel. Seasonal dripping of water could also be observed at some places which is taken in analysis.

Considering a conservative case to estimate maximum stresses on lining in the conditions observed at site a value of 0.5 is selected for K_0 (gravity field stress ratio). According to geological and geotechnical conditions, the geotechnical design parameters associated to the different ground types for each tunnel are defined and given in tables below. These geotechnical parameters associated to the different ground types were considered for the analyses.

The Hoek-Brown Failure criteria is used in analysis of rock mass parameters from intact rock parameters. ***Details have been mentioned below:***

6.1 HOEK-BROWN FAILURE CRITERION

The Hoek-Brown failure criteria is a widely used rock mass failure criterion that is based on empirical observations of the behaviour of rocks under stress. This criterion was first proposed by Hoek and Brown in 1980 and has since become an important tool for predicting the behaviour of rock masses in engineering and mining applications.

The Hoek-Brown failure criterion involves a total of 8 parameters: the uniaxial compressive strength of the rock (σ_{ci}), Intact rock parameter (m_i), Geological Strength Index (GSI), Young's modulus of rock mass (E), Poisson's ratio (μ), Disturbance factor (D), Drained cohesion (c'), Drained friction angle (φ), Absolute value of confining pressure σ'_3 at which $\psi = 0°$, Dilatancy angle (ψ_{max}) at $\sigma'_3 = 0$.

The Hoek-Brown failure criterion is particularly useful because it takes into account the effects of confinement and the brittleness of the rock mass. It has been shown to provide more accurate predictions of the behavior of rock masses under stress than other failure criteria, particularly in situations where the rock mass is heavily jointed or fractured.

The generalised Hoek-Brown failure criterion can be expressed as a non-linear relationship between the major and minor effective principal stresses, as shown below.

$$\sigma_1' = \sigma_3' + \sigma_{ci}\left(m_b \frac{\sigma_3'}{\sigma_{ci}} + s\right)^a$$

Where,

σ_1' and σ_3' are the major and minor effective principal stresses at failure;

σ_{ci} is the uniaxial compressive strength of the intact rock material and

m_b is a reduced value of the intact rock parameter m_i as given by;

$$m_b = m_i \, exp\left(\frac{GSI - 100}{28 - 14D}\right)$$

s and a are auxiliary material constants for the rock mass given by the following relationships;

$s = exp\left(\frac{GSI-100}{9-3D}\right)$ and $a = \frac{1}{2} + \frac{1}{6}\left[exp\left(\frac{-GSI}{15}\right) - exp\left(\frac{-20}{3}\right)\right]$

The Roc Data results are placed on Appendix-I , whereas the theory for Geological Strength Index (GSI), Disturbance factor (D) and Intact rock parameter (m_i) are estimated based on Hoek & Brown (2002) given in Appendix II of this report.

D is a factor which depends upon the degree of disturbance to which the rock mass has been subjected by blast damage and stress relaxation. It varies from 0 for undisturbed in situ rock masses to 1 for very disturbed rock masses. The detailed report of interpretation of intact rock property into rock mass is tabulated in Annexure-1.

7 Design Methodology

The primary purpose of any tunnel site investigation i.e., Geo-mapping, Geophysical survey and Geotechnical investigations is to obtain the maximum amount of information on rock characteristics, structural systems, and groundwater conditions. This information is important for as it enables the designer to assess the behaviour of the rock surrounding the tunnel and the type of support required to maintain the tunnel in a stable condition. With the designed rock supports the contractor can plan and schedule the construction activities to complete the work

Rock mass classification schemes were developed for over 100 years with an attempt to formalize an empirical approach to tunnel design, in particular for determining support requirements. While the classification schemes are appropriate for their original application, especially if used within the bounds of the case histories from which they were developed, considerable caution must be exercised in applying rock mass classifications to other rock engineering problems. The RMR by Bieniawski's and Q-value by Barton et al' are most commonly used in tunnel design.

RMR System

Bieniawski (1976) published the details of a rock mass classification called the Geomechanics Classification or the Rock Mass Rating (RMR) system. The following six parameters are used to classify a rock mass using the RMR system:

1. Uniaxial compressive strength of rock material.
2. Rock Quality Designation (RQD).

3. Spacing of discontinuities.
4. Condition of discontinuities.
5. Groundwater conditions.
6. Orientation of discontinuities.

The RMR value of rock mass is the summation of all these six parameters. The Rock Quality is based on the RMR value of rock mass and based on the Rock Quality support system is proposed by the Bieniawski. The relation between RMR rating and rock Quality is given below in table.

Table 3 Relation between RMR and Rock Quality

RMR (Rock Mass Rating)	**Rock Quality**
81-100	Excellent
61-80	Good
41-60	Fair
21-40	Poor
0-20	Very poor

The Guidelines for excavation and support of 10 m span rock tunnels in accordance with RMR system is given in table below.

Table 4 Support based on RMR Value

Rock mass class	**Excavation**	**Rock bolts (20 mm diameter, fully grouted)**	**Shotcrete**	**Steel sets**
I - Very good rock RMR: 81-100	Full face, 3 m advance.	Generally, no support required except spot bolting.		
II - Good rock RMR: 61-80	Full face, 1.5-3.0 m advance. Complete support 20 m from face.	Locally, bolts in crown 3 m long, spaced 2.5 m with occasional wire mesh.	50 mm in crown where required.	None.
III - Fair rock RMR: 41-60	Top heading and bench 1.5-3 m advance in top heading. Commence support after each blast. Complete support 10 m from face.	Systematic bolts 4 m long, spaced 1.5 - 2 m in crown and walls with wire mesh in crown.	50-100 mm in crown and 30 mm in sides.	None.

IV - Poor rock RMR: 21-40	Top heading and bench 1.0-1.5 m advance in top heading. Install support concurrently with excavation, 10 m from face.	Systematic bolts 4-5 m long, spaced 1-1.5 m in crown and walls with wire mesh	100-150 mm in crown and 100 mm in sides.	Light to medium ribs spaced 1.5 m where required.
V – Very poor rock RMR: < 20	Multiple drifts 0.5-1.5 m advance in top heading. Install support concurrently with excavation. Shotcrete as soon as possible after blasting.	Systematic bolts 5-6 m long, spaced 1-1.5 m in crown and walls with wire mesh. Bolt invert.	150-200 mm in crown, 150 mm in sides, and 50 mm on face.	Medium to heavy ribs spaced 0.75 m with steel lagging and forepoling if required. Close invert.

Q- System

Based on an evaluation of a large number of case histories of underground excavations, Barton et al (1974) of the Norwegian Geotechnical Institute proposed a Tunnelling Quality Index (Q) for the determination of rock mass characteristics and tunnel support requirements. The numerical value of the index Q varies on a logarithmic scale from 0.001 to a maximum of 1,000 and is defined by:

$$Q = \frac{RQD}{Jn} X \frac{Jr}{Ja} X \frac{Jw}{SRF}$$

Where,

RQD is the Rock Quality Designation

J_n is the Joint set number

J_r is the joint roughness number

J_a is the joint alteration number

J_w is the joint water reduction factor

SRF is the stress reduction factor

Estimated support categories based on the tunnelling quality index Q after Grimstad and Barton, 1993, reproduced from Palmstrom and Broch in 2006. The Chart representing the rock type and support proposed based on the Q-value is given in the Figure below.

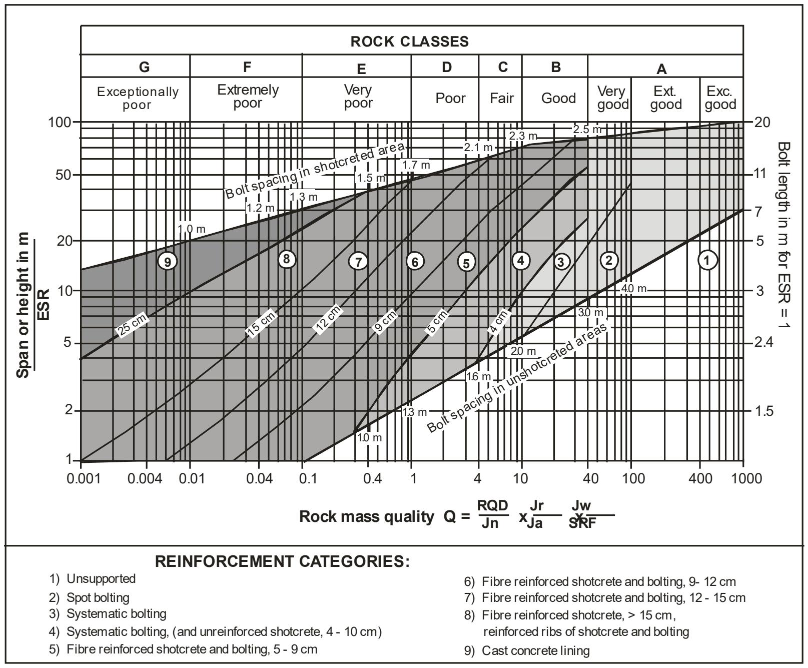


Figure 118 Showing the Rock Type based on Q value.

Thus, following values are interpreted based on considering Q for classification of Tunnel section.

Table 5 Support Class Recommendation For Tunnel Primary Lining

Support Class	Support Class Listing	Modified Support Class on account of RMR & Q classification	Advance length	Bolt Length (m)	Spacing(m)	M 25 Shot crete (cm)	Wire Mesh (150 x 150 x 6)	Lattice Girder 70/16/25 @ 11.5 kg/m	Fore poling 25 mm dia
1	Unsupported	I	Full face, 3 m advance.	NA	NA	NA	NA	NA	NA
2	Spot Bolting			NA	NA	NA	NA	NA	NA
3	Systematic Bolting	II	Full face, 2m advance. Complete support 20 m from face.	3	2.0	5 cm	NA	NA	NA
4	Systematic Bolting and unreinforced shotcrete 4-10 cm			3	2.0	5 cm	NA	NA	NA
5	Fibre Reinforced Shotcrete and bolting 5-9 cm	III	Full face, 2m advance. Complete support 10 m from face. Commence support after each blast.	4	2.0	10 cm	Yes	NA	NA
6	Fibre Reinforced Shotcrete and bolting 9-12 cm			4	2.0	10 cm	Yes	NA	NA
7	Fibre Reinforced Shotcrete and bolting 12-15 cm	IV	Full face, 1.5 m advance. Install support concurrently with excavation, 10 m from face.	4	1.5	15 cm	Yes	Yes	NA
8	Fibre Reinforced Shotcrete > 15 cm reinforced ribs (70/16/25 @ 11.5 kg/m) of shotcrete and bolting			4	1.5	15 cm	Yes	Yes	NA
9	Cast concrete lining	V	Multiple drifts 0.5-1.5 m advance in top heading. Install support concurrently with excavation. Shotcrete as soon as possible after blasting.	6	1.5	20 cm	Yes	Yes	Yes

Therefore based on RMR and Q, following support classes are defined for calculation of quantities:

PORT CLASS	AREA (M^2)	EXCAVATION STAGE	AVERAGE ROUND LENGTH (Longitudinal Tunnel Direction)	SHOTCRETE (M-25 or 30) As per Design	WIREMESH 150X150X 6MM	ROCK BOLTS/ ROUND	LATTICE GIRDERS PER ROUND	FORE POLES PER ROUND
SC-I	51.15	Full Face	3 m	50mm (SFRC Lining)	-	Spot Bolting wherever required	-	-
SC-II	52.16	Full Face	2 m	100mm (SFRC Lining)	-	SN, Fy>200kN Length:3 m @ 2 m c/c (25mm Día)	-	-
SC-III	54.22	Full Face	2 m	150mm (SFRC Lining)	1 layer	SN, Fy>200kN Length:4 m @ 2 m c/c (25mm Día)	-	-
SC-IV	54.22	Full Face or Heading & Benching (As per requirement)	1.5 m	200mm (SFRC Lining)	1 layer	SN/SDA, Fy>200kN Length:4 m @ 1.5 m c/c (25 mm Día)	1 set 70/16/25	- -
SC-V	56.61	Top Heading	1.5m	250mm (SFRC Lining)	2 layers as per design	SDA Fy>200kN Length:6m @ 1.5 m c/c (32 mm Día)	1 set 70/16/25	Forepoles SN/SDA, Fy>200kN Length:4m @ (300m c/c) Pipe Roofing OD-114.3 dia
		Benching	3 m					
SC-VI	56.61	Top Heading	1.5m	300mm (SFRC Lining)	2 layers as per design	SDA Fy>200kN Length:6 or 9 m @ 1.5 m c/c (32 mm Día)	ISMB RIB 250 X 125 or more as per design	Forepoles SN/SDA, Fy>200kN Length:4m @ (200-300m c/c) Pipe Roofing OD-114.3 dia
		Benching	3 m					

Note: It is to be noted that in Support Class IV, V & VI, items such as Pipe Roofing, Water Inflatable bolts, fiber glass bolts, percussion drilling and consolidation grouting have been taken to account design requirements.

Following loads are considered for the primary support design in the numerical calculations:

7.1 Earth Pressure

Ground loads on initial stress state given by a maximum overburden according to cross section considered and a coefficient of earth pressure at rest of 0.5 is considered. Ground loads onto the tunnel cross section are calculated by definition of a relaxation factor, which simulates the "volume loss" and stress relaxation due to excavation, followed by a complete relaxation of the ground inside of the excavation area. The earth pressure for the analysis is derived in consideration of overburden and unit weight of rock mass.

7.2 Groundwater pressure

During geotechnical investigations and site visit, it was observed that water in tunnels was limited to dripping conditions (with seasonal occurrences). As the strata is competent, water pressures are not expected to develop beyond tunnel linings. Hence, the tunnels are designed as drained tunnels, for which water pressures are not considered as design load case. Additionally, drainage path with use of waterproofing membrane and drains will ensure that no water pressure builds up on tunnel linings.

7.3 Live load

Any live loads if applicable are considered in the design for the design of primary lining. For these tunnels there are no live loads expected.

7.4 Seismic Load

With regard to the temporary works character of the outer lining (primary support) seismic loading is not applicable here. Whereas the same is considered in permanent lining design.

8 Safety Factors

For all loads relevant to the primary support, a load factor of 1.0 is considered due to the temporary nature of the primary structures.

For design of the primary (temporary) support, the following material factors have been applied:

Table 6

Steel (reinforcement, rockboltsetc.):	1.15(applied to yield strength)
Shotcrete:	1.50

9 Proposed support systems

The following properties of rock support elements are considered for the primary support design:

9.1 Shotcrete

Specified compressive strength after 28 days is corresponding to concrete grade M25, characteristic compressive strength fck = 25 N/mm2, according to IS 456:2000.

Young's modulus:	E = 25000 MPa
Poisson's ratio:	ν = 0.2
Unit weight:	γ = 24 kN/m3

9.2 Reinforcement Steel

Steel reinforcement for shotcrete: Wire mesh (welded steel wire fabric): Grade Fe 500D, according to IS 1786:2008

Mesh width: 150 mm x 150 mm; bar diameter – 6mm (according to IS 4948)

Minimum yield strength: fy =500.0 N/mm2

9.3 Rock Bolts

Fully grouted rock bolts such as SN bolts or self-drilling (SD) bolts are used. SN bolts are considered with tensile capacities as mentioned in drawings and specifications.

9.4 Lattice girders

Lattice girders used in the design are 70/16/25 type three legged systems.

9.5 Fore poling.

Fore poling for the tunnels is proposed with 4m length 25 mm dia bars (min. Fy = 210 kN/mm2) having 1m overlap, 300-400 mm c/c distance between bars and 110^{o}coverage at crown.

9.6 Wire mesh with clamps

Wire mesh (hexagonally twisted) with Zinc coating and clams are provided to bottom two slope to avoid any rock fall on the track. This will arrest any such situation due to natural weathering of rock surface during design life of the project.

10 Calculations

10.1 Results and support summary

The results of the empirical analyses are given in below. Five support classes have been designed corresponding to all anticipated ground types for each tunnel.

Tables below shows the basis of calculation of Q value based on three approaches used for geotechnical assessment,

a) Geomapping
b) Geophysical investigation
c) Drilling data bore logs.

Based on the above-mentioned approaches, support for each tunnel section chainage wise is derived and the adopted value based on average/ most appropriate of these values is concluded.

The tunnel has been divided into two sections based on above mentioned parameters. For global stability of portals support class V proposed at each portal location. On interpolation of all results following is concluded. Similar quantities are computed in Bill of Quantities. It may please be noted that Kinematic analysis of Tunnels is not performed as rock exposures at tunnel portals and intermediate chainage is not fully exposed and the data is not sufficient for analysis and during excavation the geologist engaged may be required to provide adequate measures considering the site condition. However, as per geology and other governing parameters the results and corresponding quantities are considered for present condition.

S NO.	TUNNEL TYPE	Governing Bore Hole	GEOPHYSICAL RESULTS			GEOMAPPING RESULTS	DRILLING RESULTS	Adopted Results	Chainage from	Chainage to	WATER LEVEL	Remarks /Support Type	
Unit	T = TUNNEL	BH No.	ERT SURVEY	VELOCITY (m/sec)	Q RATING	Q RATING	Q RATING	Q Rating	m	m	m	Type	Support
1	TUNNEL-9	BH-1	ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows vertical changes in resistivity values and lower values in the middle layer of the profile.	2000	0.1-1.0	1.0 - 4.0	4.0-10.0	0.01-0.001	34140	34210	12.4	The upslope area has also occupied by thick forest cover/vegetation and having moderate to steep slope towards portal. The portal slope area of proposed portal is covered with thick slope debris cum hill slope wash material represented by pebbles to boulders of Basalt embedded in silty clay matrix. The overburden material is unconsolidated to semi-consolidated in nature consisting of pebbles, cobbles, boulders of Basalt and other rock fragment mixed with soil	SC-V
		BH-2		3300	0.1-1.0	4.0-10.0	1.0-4.0	0.4-0.01	34210	34610	12.4		SC-IV
				3300	0.1-1.0	10.0-40.0	1.0-4.0	4-0.4	34610	35140			SC-III
				3000	0.01-0.1	10.0-40.0	1.0-4.0	0.4-0.01	35140	35540			SC-IV
		BH-3		2000	0.01-0.1	1.0 - 4.0	1.0-4.0	0.01-0.001	35540	35610	15.5		SC-V
2	TUNNEL-9A	BH-1	ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the center of the profile.	1600	0.01-0.1	1.0 - 4.0	1.0-4.0	0.01-0.001	36290	36360	-	Similar to Tunnel-9	SC-V
		BH-1 & BH-2		2000	0.01-0.1	4.0-10.0	1.0-4.0	0.4-0.01	36360	36470	-		SC-IV
		BH-2		1600	0.01-0.1	1.0 - 4.0	1.0-4.0	0.01-0.001	36470	36540	27		SC-V
3	TUNNEL-10	BH-1	ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the center-right of the profile.	2100	0.01-0.1	1.0 - 4.0	1.0-4.0	0.01-0.001	36820	36890	7	The upslope area has also occupied by thick forest cover/vegetation and having steep slope towards portal. The portal slope area of proposed portal is covered with thick slope debris cum hill slope wash material represented by pebbles to boulders of Basalt embedded in silty clay matrix. The overburden material is unconsolidated to semi-consolidated in nature consisting of pebbles, cobbles, boulders of Basalt rock fragment mixed with soil matrix. The visually estimated ratio of the coarse: fine material is 80:20 respectively.	SC-V
		BH-2		2000	0.01-0.1	4.0-40	4.0-10.0	0.4-0.01	36890	37150	-		SC-IV
		BH-3		2000	0.01-0.1	1.0 - 4.0	4.0-10.0	0.01-0.001	37150	37220	10.12		SC-V
4	TUNNEL-11	BH-1	ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the right of the profile.	2100	0.01-1.0	1.0 - 4.0	1.0-4.0	0.01-0.001	37380	37450	8	The upslope area has also occupied by thick forest cover/vegetation and having steep slope towards portal. The portal slope area of proposed portal is covered with thick slope debris cum hill slope wash material represented by pebbles to boulders of Basalt embedded in silty clay matrix. The overburden material is unconsolidated to semi-consolidated in nature consisting of pebbles, cobbles, boulders of Basalt rock fragment mixed with soil matrix. The visually estimated ratio of the coarse: fine	SC-V
		BH-2		2800	0.1-1.0	4.0-40	1.0-4.0	0.4-0.01	37450	37650	2		SC-IV
		BH-3		2800	0.1-1.0	4.0-40	1.0-4.0	4-0.4	37650	37920	8		SC-III
		BH-4		2500	0.1-1.0	4.0-40	1.0-4.0	0.4-0.01	37920	38120	7.5		SC-IV
		BH-5		2800	0.1-1.0	1.0 - 4.0	1.0-4.0	0.01-0.001	38120	38190	15		SC-V
5	TUNNEL-12	BH-1	ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the left and right of the profile.	2800	0.1-1.0	1.0 - 4.0	1.0-4.0	0.01-0.001	38510	38580	14	The upslope area has also occupied by thick forest cover/vegetation and having steep slope towards portal. The portal slope area of proposed portal is covered with thick slope debris cum hill slope wash material represented by pebbles to boulders of Basalt embedded in silty clay matrix. The overburden material is unconsolidated to semi-consolidated in nature consisting of pebbles, cobbles, boulders of Basalt rock fragment mixed with soil matrix. The visually estimated ratio of the coarse: fine	SC-V
		-		2800	0.1-1.0	4.0-40	1.0-4.0	0.4-0.01	38580	38980	-		SC-IV
		-		2800	0.1-1.0	4.0-40	1.0-4.0	4-0.4	38980	39320	-		SC-III
		-		2800	0.1-1.0	4.0-40	1.0-4.0	0.4-0.01	39320	39720	14		SC-IV
		-		2800	0.1-1.0	1.0 - 4.0	1.0-4.0	0.01-0.001	39720	39790	14		SC-V
6	TUNNEL-12A	BH-1	ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the left and right of the profile.	2500	0.1-1.0	1.0 - 4.0	4.0-10.0	0.01-0.001	40540	40590	10	Similar to Tunnel-12A	SC-V
		BH-1 & BH-2		2500	0.1-1.0	4.0-40	4.0-10.0	0.01-0.001	40590	40630	-		SC-V
		BH-2		2500	0.1-1.0	1.0 - 4.0	4.0-10.0	0.01-0.001	40630	40680	12		SC-V

7	TUNNEL-13	BH-1	ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows primarily vertical changes in resistivity values and lower values in the middle section of the profile, after a high resistivity top.	2700	0.1-1.0	1.0 - 4.0	4.0-10.0	0.01-0.001	42800	42870	10	The upslope area has also occupied by thick forest cover/vegetation and having steep slope towards portal. The portal slope area of proposed portal is covered with thick slope debris cum hill slope wash material represented by pebbles to boulders of Basalt embedded in silty clay matrix. The overburden material is unconsolidated to semi-consolidated in nature consisting of pebbles, cobbles, boulders of Basalt rock fragment mixed with soil matrix. The visually estimated ratio of the coarse: fine material is 90:10 respectively.	SC-V
		BH-1 & BH-8		2600	0.1-1.0	4.0-40	4.0-10.0	0.4-0.01	42870	43320	10		SC-IV
		BH-1 & BH-8		3300	0.1-1.0	4.0-40	4.0-10.0	4-0.4	43320	43880	10		SC-III
		BH-1 & BH-8		2400	0.01-0.1	4.0-40	4.0-10.0	0.4-0.01	43880	44330	10		SC-IV
		BH-8		2400	0.01-0.1	1.0 - 4.0	4.0-10.0	0.01-0.001	44330	44400	10		SC-V
8	TUNNEL-14	BH-1	ERI profile length of 177m with electrode spacing of 3m, using a 60-electrode system was conducted. The profile shows lateral changes in resistivity values and lower values in the left and center-right of the profile.	RCC					55700	55840	-	The upslope area has also occupied by thick forest cover/vegetation and having gentle to moderate hill slope towards portal. The portal slope area of proposed portal is covered with thick slope debris cum hill slope wash material represented by pebbles to boulders of Basalt & followed by minor rock exposure. The overburden material is unconsolidated to semi-consolidated in nature consisting of pebbles, cobbles, boulders of Basalt and other rock fragment mixed with soil matrix.	Cut & Cover
				4000	0.1-10	1.0 - 4.0	4.0-10.0	0.01-0.001	55840	55910	-		SC-V
		BH-2		3500	0.1-10	4.0-40	4.0-10.0	0.4-0.01	55910	56410	-		SC-IV
				5100	0.1-10	4.0-40	4.0-10.0	4-0.4	56410	57420	-		SC-III
		BH-3		4000	0.1-10	4.0-40	4.0-10.0	0.4-0.01	57420	57920	-		SC-IV
		BH-4		5100	0.1-10	1.0 - 4.0	4.0-10.0	0.01-0.001	57920	57990	-		SC-V

Table 7 PRIMARY LINING OF TUNNEL T-9 to T-14 BASED ON Q SYSTEM

11 Secondary Lining Approach and Methodology

The initial shotcrete lining for a NATM tunnel is designed and installed as temporary support for carrying ground loads induced by tunnel excavation. The initial shotcrete lining may degrade over time, particularly in aggressive environments due to the corrosion of steel reinforcement subject to high chloride conditions or deterioration of the shotcrete because of the presence of sulphates in the ground or groundwater. This degradation of the initial shotcrete lining causes redistributions of stresses and strains or loads in the lining and adjacent ground, and possibly additional deformation of the lining. As a result of the degradation and additional deformation of the initial lining, the loads originally developed in the initial lining will redistribute to both the adjacent ground and secondary lining over the long term

The magnitude of load transferred from the initial lining to the secondary lining, also called the load sharing, depends on many factors, including:

- Available bond and normal and shear stiffness of the interface
- Ground conditions such as rock mass strength/stiffness
- Relative stiffness between the initial and secondary linings
- In situ stress conditions such as the ratio of horizontal-to-vertical stresses (Ko)
- Tunnel shape (e.g., circular and horseshoe shaped).

The secondary lining extrados will be in contact with the waterproofing membrane and potential groundwater in the event of a breach of the waterproofing membrane. The intrados is exposed to the internal atmospheric conditions of the individual tunnel cross passage. The primary deterioration mechanism which risks secondary lining durability is carbonation. Secondary lining extrados is not accessible for visual inspection and/or repair while the intrados will be accessible for inspection, monitoring, and maintenance but only during limited planned engineering possessions of the tunnel.

The sprayed concrete primary lining is a temporary element which is to stabilise the ground during the construction period, providing support until the permanent secondary lining is installed. The primary lining has no permanent support function.

The secondary tunnel lining is designed after considering the factors like the deformation modulus, UCS, loads acting on an approach that enables the specific characteristics of a tunnel lining implemented using numerical modelling to be considered during its design.

12 Design loads and safety factors

Following loads are considered for the primary support design in the numerical calculations:

12.1 Earth Pressure

Ground loads on initial stress state given by a maximum overburden according to cross section considered and a coefficient of earth pressure at rest of 0.5 is considered. The earth pressure for the analysis is derived in consideration of overburden and unit weight of rock mass.

12.2 Live loads

Any live loads if applicable are considered in the design for the design of primary lining. For these tunnels there are no live loads expected.

12.3 Seismic loading

The project area lies in Zone 2 as per IS 1893-I (2002). The earthquake loading is applied as per the code and vertical seismic coefficient used for analysis is 0.06 and horizontal seismic coefficient used in 0.04.

12.4 Groundwater pressure

For "drained" tunnels, water pressures are not considered as design load case as the water in tunnels is observe in dripping conditions only with seasonal appearance. Additionally, drainage system in tunnel shall ensure that no water pressure builds up.

12.5 Safety Factors

For all loads relevant to the secondary support, a load factor of 1.3 will be considered due to the permanent nature of the secondary lining.

For design of the secondary (permanent) support, the following material factors have been applied:

Table 8

Steel (reinforcement etc.)	1.15(applied to yield strength)
Concrete:	1.50

13 Proposed support systems

The following properties of rock support elements are considered for the secondary support design:

13.1 PCC lining

The stretches of tunnels which are in good rock conditions were analysed for stresses expected on lining and PCC lining is proposed where there are no stresses expected and rock mass undergoes full relaxation during application of primary support. The compressive strength of PCC lining proposed is M30 after 28 days, characteristic compressive strength fck = 30 N/mm2, according to IS 456:2000.

For Grade III rock, PCC Lining was modelled in RS2 software for the worst Geotechnical Parameters and the resultant forces & Moments are checked for the adequacy of the PCC lining. The Model s attached in this report below.

13.2 RCC lining

RCC lining is proposed for first 50-70m (approx.) of tunnel from both ends i.e., tunnel portals to provide stiffer openings to the tunnel entrance and to cater the possibility of finding weathered rock at low overburden region. Additionally, where the tunnels are going through weaker rock strata and ground has capacity to relax in long term the RCC lining is proposed. The steel used in Fe 500/Fe500D as per IS 1786: 2008.

For Grade V rock (weaker and weathered rock types), RCC Lining was proposed and modelled in RS2 software for the worst geotechnical parameters encountered in the project and the resultant forces & moments are checked for the adequacy of the RCC lining. The Model is attached in this report.

14 Calculations

14.1 Numerical Modelling

The software used for the numerical analysis is the two-dimensional finite element software RS2 version 9 from Ro science. This software is intended for 2D elasto-plastic finite element stress analysis for underground excavations in rock or soil.

14.1.1 Material models

Material models are used to describe the behaviour of the ground that is suitable constitutive laws to account for the elastic, as well as inelastic ranges of the respective materials.

The material behaviour of the ground is simulated according to the material law of Mohr-Coulomb in this project.

14.1.2 Ground Loads – Representation of the Construction Sequence

Tunnel excavation causes a disturbance of the initial stress state in the ground and creates a three-dimensional stress regime in the form of a bulb (arching effect) around the advancing tunnel face.

The extent of the stress disturbance around an active heading depends mainly on ground conditions, size of the excavation and length of round. The design according to NATM principles dictates limits on excavation size and length of round and prescribes installation of primary support elements immediately after the excavation of each individual round. Primary support elements are therefore installed within the region of a load-carrying arch around the newly created opening in the region where some pre-deformation has occurred.

As the excavation of the tunnel advances the shotcrete hardens from an initially “green” shotcrete and becomes fully loaded at a certain distance from the face. Such sequencing combined with the early support installation contributes to the development of the self-supporting capability of the ground. It further helps in minimizing deformations and ground loosening. It is therefore important to portray the excavation and support sequencing closely in the numerical analyses.

Further, to design the secondary lining, it is assumed that the primary lining does not exist, and the stresses post relaxation of rock are taken by the secondary lining itself.
Details of ground type with corresponding support class have been summarized in table given below.

Table 9 Ground type and associated excavation sequences

Ground Type	Support class	Excavation method
Grade I	As specified in the drawings	Full face
Grade II	As specified in the drawings	Full face
Grade III	As specified in the drawings	Full face
Grade IV	As specified in the drawings	Full face/Heading & Benching
Grade V	As specified in the drawings	Heading and Benching
Grade VI	As specified in the drawings	Heading and Benching and sometimes Invert

Table 10 Calculation stages for numerical analyses

Stage No.	Description of calculation stages
1	Grid set up and initial stress field
2	Face Excavation
3	Application of Primary Support Shotcrete, wire mesh, lattice girder rock bolt (only if the deformation in the rock pass is resulting in plasticization of ground near the tunnel)
4	Deactivation of primary support and application of secondary support.

14.1.3 Limit state analysis

The analysis for secondary lining is performed for limit state with required factor of safety of 1.5.

14.1.4 Lining Forces

From the numerical analyses, sectional forces (axial forces and shear forces) and bending moments of the lining are evaluated. The combinations of these sectional forces and bending moments are used to evaluate the capacity of the lining.

Based on this evaluation, the adequacy of the lining thickness and its reinforcement (if any) is assessed. The lining will be reinforced as required by the analysis.

The structural design is carried out in accordance with IS 456:2000 Plain and Reinforced Concrete Code of Practice and EN 1992-2005.

Partial safety factors for materials for ultimate limit states are adopted according to Indian codes IS 456- 2000.

Table 11 Partial factors for materials for ULS

Load Combination	Concrete	Reinforcement Steel
Ordinary Load Combination	1.5	1.15

The minimum concrete covers to all reinforcement (main and distribution reinforcing bars) considering the exposure conditions are adopted as follows:

- Concrete exposed to earth (external face) 50 mm , 75 mm for Foundation
- Concrete not exposed to earth (internal face) 50 mm

15 Portal Slopes Design basis and working

15.1 RDSO Standards for portal design

The evaluation of portal locations for mountain tunnels is among the most crucial considerations during route selection and structural layout planning. The development of spatial information technology has provided a more objective approach for assessing the slope stability of potential portal sites. An empirical method suggested by RDSO, for an infinite slope was integrated into the geographical information system for evaluating the stability of critical wedges. The proposed method provides a reasonable estimation comparable with that provided by the stability software's. The results of applying this method to tunnel portals where slope instability is significant. For potential portal site evaluation, the proposed method facilitates the rapid estimation of safety factors for various slope designations, which is useful for site selection. Tunnel proposed at Ratlam-Khandwa section; therefore, number of portals (one at each end) need to be analysed for structure stability.

Slope failure of cuttings is a complex phenomenon. The failure of rock slopes is controlled by geological features such as bedding planes and joints which divide the rock body up into a discontinuous mass. Under these conditions, the failure path in rocks is normally defined by one or more of the discontinuities. However, in the case of soil, a strongly defined structural pattern does not exist and therefore, the failure surface is free to find the path of least resistance through the slope.

16 Slope Stability

The slope stability is discussed for soils and rocks separately.

16.1 Soils

Failure in soils is rather simple i.e., circular in homogeneous materials & non-circular or planar in layered soils. In general, failure along a non-circular surface can be anticipated if the soil deposit is non-homogeneous or if there are discontinuities within the slope. A predominantly planar slip surface may be expected in shallow natural slopes. Failure generally takes place along slip surfaces parallel to the slope.

The stability of any slope is governed by several factors such as the nature of materials comprising the slope, the history of slope formation, the movement of water through the soil and the steepness of the slope. The most common type of failure in soil is that due to sliding and it is often referred to as a shear failure along a surface of sliding. The tendency for instability or failure is a consequence of gravity (self-weight of the soil or soils comprising the slope) and any other external loads (e.g., a structure on the crest of the slope, water pressure in tension cracks or an earth tremor). This tendency is resisted by the shear strength of the soil or soils comprising the slope. In a stable slope there is no continuous surface along which the average shear strength is less than the average shear stress caused by gravitational and external loads. Zones of overstress could be the starting points for local, partial, or complete failure. The formation and propagation of such zones is sometimes crucial for the safety of a soil mass. To understand the conditions governing stability fully, it is useful to consider geological, geotechnical, and environmental factors.

The soil adjacent to the ground and slope surfaces may be quite strong but there may be a bedding plane or a fault or an ancient surface of sliding within the slope. An understanding of local geology facilitates possible detection of such features at a given site.

The shear strength that can be mobilized is governed by the permeability characteristics and the extent of drainage and volume change that can take place. Such geotechnical factors require careful attention. Infiltration of water due to rainfall increases pore water pressure and reduces the shear strength. Often slope failures occur because of heavy or prolonged rainfall.

Environmental changes near a sloping area such as deforestation, urbanization and construction of reservoirs often lead to increases in pore water pressure and other effects such as soil erosion. Filling of valleys may also disturb the natural drainage characteristics of a sloping area and contribute to instability.

It is further observed that there is no persistent ground water present across the tunnels. Seasonal dripping of water was observed at some places which is ignored for analysis purposes. K_0 (gravity field stress ratio) is considered as 0.5 for analysis purposes. Distinction must be made between short-term and long-term stability conditions, especially for slopes of cohesive soil. In the field, the end of construction situation is usually a short-term stability condition. The long-term condition is when ‘excess’ or ‘transient’ pore water pressures within a slope are fully dissipated. However, the long-term condition of equilibrium may be reached in the field after many months or years depending on the thickness of cohesive soil, its coefficient of permeability and other factors. For cuts, excavations and natural slopes, critical stability is in the long term when the factor of safety is a minimum.

Unloading or excavation causes negative excess pore water pressure. Consequently, the total pore water pressure has its lowest value at the end of construction and shear strength has its highest value at the time. In the long term, the negative excess pore water pressure reduces to zero, the total pore water pressure is increased, and the shear strength is, therefore, decreased. It is obvious that the stability of an excavation is reduced in the long term from the condition at the end of construction.

The complete dissipation of excess pore water pressures in a cohesive soil may take many years. In cohesionless soils like sand, excess pore water pressures are dissipated so rapidly that there is no need to distinguish between short-term and long-term conditions based on pore water pressure and drainage. However, this is true of static loading only. Significant excess pore water pressures may develop in such soils during earthquakes resulting in dramatic loss of shear strength.

16.2 Rocks

The properties of intact rock are changed dramatically by the presence of discontinuities such as joints, faults, and fractures. These discontinuities are planes of weakness across which there is little or no tensile strength. In essence, discontinuities break the cohesive bonds across distinct planes in the rock. On a local scale, this may cause the tensile strength to drop to zero and will usually cause significant reductions in shear strength as well as large increases in permeability. On a regional scale, discontinuities are largely responsible for the distinctive drainage patterns and major erosional features that are characteristic of faulted and jointed terrain.

In rocks, most slope failures are controlled by ever present discontinuities. Slope failures will propagate depending on the extent, pattern and types of discontinuities present in the rock mass. The orientation of these discontinuities in combination with the natural face of rock, shall bring about one or more failure mechanisms that may involve free fall, sliding or rotation of rock blocks. Therefore, discontinuities are critical for identification of potential failure mechanism in fractured rock masses. Important characteristics of discontinuities influencing the strength are orientation, spacing, size & shape of block, roughness, aperture, its in-fillings, wall strength, wall coating, and seepage through them.

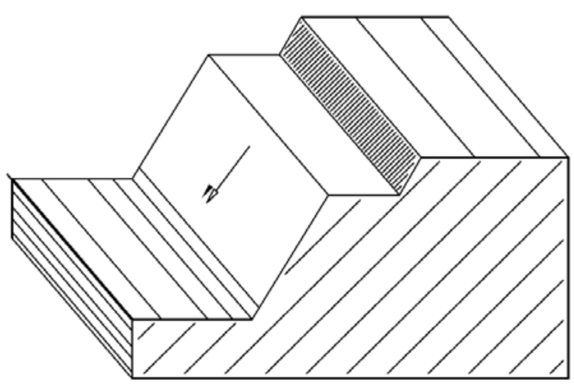
A rock mass may display one or more modes of failure depending on following factors:

a) Presence or absence of discontinuities
b) Orientation of discontinuities in relation to that of the natural or excavated face
c) Discontinuity spacing in one and three dimensions.
d) Shear strength of discontinuity walls
e) Persistence of discontinuities

Modes of Rock Failure at Portals:

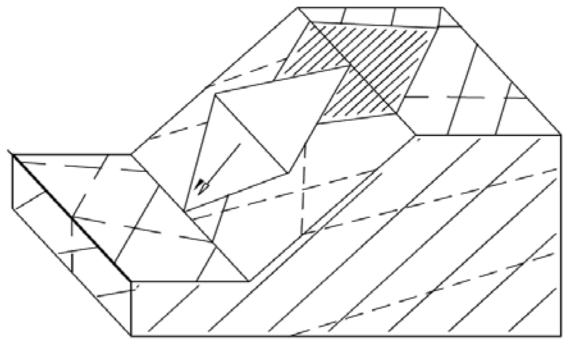
a) Plane Failure: It occurs when a geological discontinuity such as a bedding plane, strikes parallel to the slope face and dips into the excavation at an angle greater than the angle of friction. This is the one of the simplest modes of failure. For plane failure to occur in slopes there must be lateral release surfaces that will allow a block of finite size to slide out of the face. It occurs rarely in rock slopes.

PLANE FAILURE



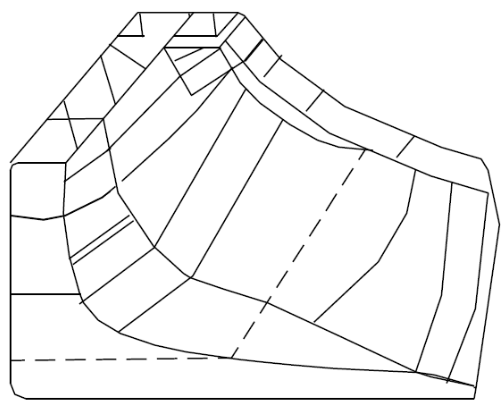
b) Wedge Failure: When two discontinuities strike obliquely across the slope face, the wedge of rock resting on these discontinuities will slide down the line of intersection, provided that the inclination of this line is significantly greater than angle friction. This is most dangerous mode of failure since no release surfaces are required. The calculation of factor in this case is more complicated than that for plane failure since the base areas of both failure planes as well as the normal forces on the planes must be calculated.

WEDGE FAILURE



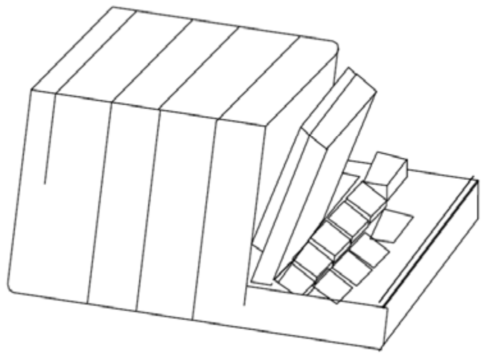
c) Circular Failure: It occurs when material is very weak or rock mass is heavily jointed or broken, the failure will be defined by a single discontinuity surface but will tend to follow a circular failure path. When the pattern of discontinuities is random circular failure modes are likely.

CIRCULAR FAILURE

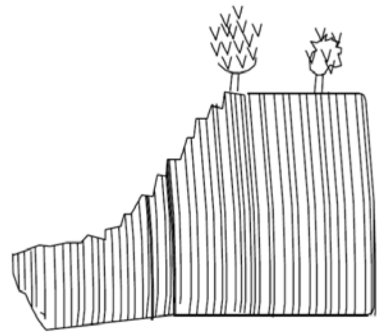


d) Toppling Failure: It occurs when vector representing the weight of block falls within the base, and inclination of plane is greater than angle of friction. Also, when rock block is tall and slender (height > width), the weight vector can fall outside the base and when this happens the block will topple i.e., it will rotate about its lowest contact edge. Toppling failure involves either one or a combination of flexural toppling and block toppling. Flexural toppling involves the overturning of rock layers like a series of cantilever beams. Block toppling involves the overturning of fracture-bounded blocks as rigid columns rather than having to fail in flexure.

BLOCK TOPPLING

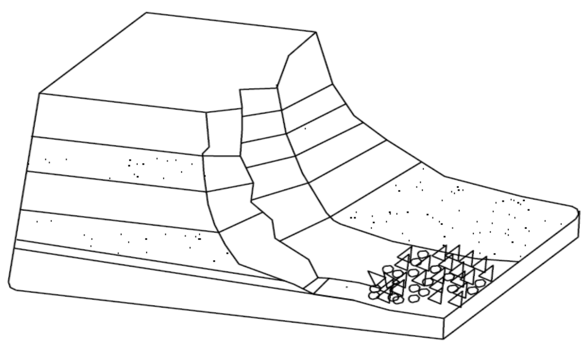


FLEXURAL TOPPLING



e) Rock Falls: Rock falls consist of free-falling blocks of different sizes which are detached from a steep rock face. The block movement includes bouncing, rolling, sliding and fragmentation. The problem in design of slopes from viewpoint of rock fall is the prediction of the paths and the trajectories of the unstable blocks which detach from the rock slope so that suitable protection measures are constructed well in advance.

ROCKFALLS



17 Design Methodology

It involves the design of following components:

a) Slopes- RDSO standard slopes has been provided as per the Geotech classification based on Geomapping, Geophysical, bore log details and site photographs.

b) Benching/Berms – RDSO standard for rocks minimum berm width of 4-6 m. It is advisable to provide berms in soil slopes at every 6 to 7 m height to break monotony of slopes. Width of first berm from formation may be kept as 5 m and that of subsequent berms as 4 m. In cuttings where soil-strata are in top portion and weathered/jointed rock in bottom portion, it is essential to provide 5 to 6 m berm at soil-rock interface.

c) erosion and slope protection work – providing retaining walls, steel wire net with u clamps and providing berms at adequate height interval.

d) side drains- Side drain width is generally standard 1.2 m wide on top, 0.6 m at bottom. The depth is min 0.3 m, with deeper drains as per longitudinal slope depending upon length of cutting. Sub-surface longitudinal drains may be required where blanket layer has been provided.

e) boundary drains- Rainfall, percolation or streams that flow outside the boundaries of the cutting have a grave potential of affecting the behaviour of the cutting in immediate or even distant future. Effective steps need to be taken to avert any eventuality of ingress of any such water that has not been catered for in the design. This job is to be accomplished by provision of boundary or peripheral drains. These drains are also called catch water drains.

18 Analysis Results

1. This is the preliminary stage design based on the data available from Geological mapping, Seismic Refraction Survey and Geotechnical investigations. As per initial studies and best thumb rule practices on observational approaches, support system is derived for each tunnel slope.

   Hence following supports are provided in portal drawings.

1. The portal support quantities have been considered 1H:2V slope and 100 mm shotcrete + wiremesh (150x150x6) along with perforated pipe and rock bolts at 3 m c/c spacing staggered.
2. The detailed analyses must be carried out during detailed design and further modifications can be made during construction stage based on the site conditions.
3. Excavated slope surface is assumed to be free draining and no water pressure shall be allowed to be built up behind the shotcrete sealing or in the ground close to the excavated face. For this, drainage measures such as drainage drillings and/or weep holes must be applied. It is critically important to implement and maintain proper drainage arrangement along the excavated slopes during the execution of the project.
4. Monitoring program including inclinometers and survey points shall be implemented during construction stage to detect any possible creeping or slope movements.

19 Portal cross- sections

Major rock cuts require detailed subsurface investigation to know the type & condition of rock strata before taking up the excavation. As and when excavation progresses, additional geological information helps in deciding rock slope, at various levels, by carrying out tests like compressive strength, petrographic examination of samples, soundness tests etc.

The blasting in rock strata plays a very significant role in slope stability. Uncontrolled blasting often results in shattering of rock mass, by means of opening of joints, developments of tension cracks, rough, uneven contours, overbreak's, overhangs etc. The results of blast shock wave, along various discontinuities can lead to loosening of the rock.

Rough guide for adopting the slopes or cuts in rock is given in table below. In adopting this table, caution must be exercised and such factors as the influence of dip in relation to the inclination of the slope face, the nature of joints etc. must be kept specially in mind. However, it would lead to safer and economical rock slopes if proper design methods are adopted to evaluate the stability of rock slopes as well.

Berms are provided to divide the long slopes into segments of short slopes which reduce pressure at the toe of the cuts, thus increasing the stability.

Slope cuts have been analysed by correlating their geotechnical properties with the range of permissible slope, and berms with bench heights as per RDSO standards. Also, RDSO recommends 1:2 (H: V) in mixed Basalt rock conditions and same has been analysed with support system for calculation of factor of safety.

Figure 119 Tunnel Approach cutting quantity and Cross Sections at Portal P-1 & 2

Sl. No.	Rock Type	Range of permissible slope (H : V)
A.	**Sedimentary Rocks**	
1.	Massive sand stones and lime stones	0.25 : 1 to 0.50 : 1
2.	Jointed/Inter bedded/Layered sand stones, lime stone & shales	0.50 : 1 to 0.75 : 1
3.	Massive clay stone and silt stone	0.75 : 1 to 1 : 1
B.	**Igneous Rocks**	
1.	Massive Granites & Basalts	0.25 : 1
2.	Jointed Granite, Jointed Basalt	0.50 :1
C.	**Metamorphic Rocks**	
1.	Gneiss, Schist and Marble	0.25 : 1 to 0.50 : 1
2.	Slate	0.50 : 1 to 0.75 :1
D.	**Weathered Rocks (All types)**	1:1

Figure 120 Slope recommendation for slope stability

20 Conclusion

The rock support systems for Tunnels are so provided such that it satisfies the factor of safety criteria. Analysis result shows that at portal slopes are stable.

The geotechnical parameters considered for the analyses are sensitive to the site conditions and susceptible to further modifications during construction stage.

Excavated slope surface is assumed to be free draining and no water pressure shall be allowed to be built up behind the shotcrete sealing or in the ground close to the excavated face. For this, drainage measures such as drainage drillings and/or weep holes must be applied. It is critically important to implement and maintain proper drainage arrangement along the excavated slopes during the execution of the project.

The slope stability analyses are carried out for critical sections for portals. Any change in the portal location from what have been analysed would require rework of slope stability analysis.

Monitoring program including inclinometers and survey points shall be implemented during construction stage to detect any possible creeping or slope movements.

21 Construction Methodology for Short Tunnels (1-2km approx.)

21.1 NATM Tunnel with mechanical excavation

NATM is recommended for this tunnel, as nearly all the tunnel sections are identified with hard rock masses some are acquainted with weathered rock, therefore in such tunnels, mechanical excavation is proposed for tunnels with rock class V at portal locations.

The construction methodology for “NATM Tunnel with mechanical excavation” includes following steps:

1. Excavating the ground profile at 2V:1H in layers of depth 2m at a time and providing support arrangement at the slope for slope stability as mentioned in report and detailed slope arrangement drawings before each next layer of excavation.
2. Ensuring provision of relief holes and perforated drainage pipe wrapped in geotextile membranes as Tunnel having water level at shallow depth.
3. Once the portal construction is complete, tunnel construction will commence.
4. Excavation sequences, enlargement of excavation profiles for allowing displacement of the surround rock mass, subdivision of headings, amount and means of rock support can be adapted rather easily and quickly to the actual ground conditions encountered. Additional measures built in at the heading face (e.g., grouting, dewatering, installation of pipe roof umbrellas, shotcrete lining with yielding elements) can cope with adverse conditions in fault zones.
5. Line positioning.
6. dust removal by ventilation
7. Installing primary supports such as shotcrete and spot bolts, wherever required. The support system may vary as per the site geological conditions and on recommendation of engineering geologist.
8. building the RCC lining as the secondary lining using moveable shuttering.

21.2 NATM Tunnel with drilling and blasting (1-2km approx.)

NATM is recommended for this tunnel, as nearly all the tunnel sections are identified with hard rock masses, drilling and controlled blasting is proposed for tunnels with rock class III.

The construction methodology for “NATM Tunnel with drilling and blasting” includes following steps:

1. Excavating the ground profile at 2V:1H in layers of depth 2m at a time and providing support arrangement at the slope for slope stability as mentioned in report and detailed slope arrangement drawings before each next layer of excavation.
2. Ensuring provision of relief holes and perforated drainage pipe wrapped in geotextile membranes as Tunnels having water level at shallow depth.
3. Once the portal construction is complete, tunnel construction will commence.
4. False Portal shall be prepared as specified in drawings and portal support class to be followed for tunnel construction commencement.
5. Afterwards Line positioning.
6. drilling, loading, and controlled blasting.
7. dust removal by ventilation.
8. Installing primary supports such as shotcrete and spot bolts, wherever required. The support system may vary as per the site’s geological conditions and on recommendation of engineering geologist.
9. building the RCC lining as the secondary lining using moveable shuttering.

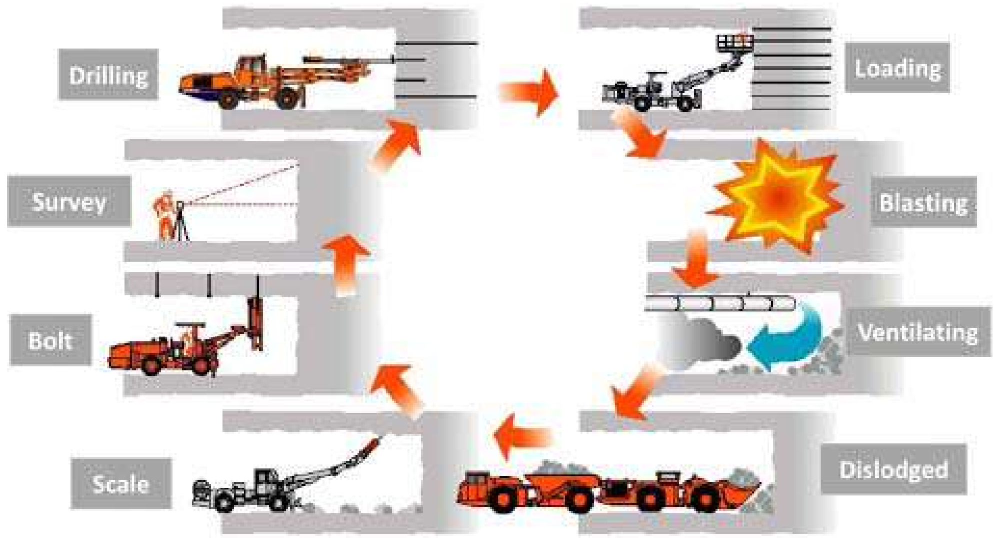


Figure 121 Construction Methodology for NATM Tunnels with mechanical excavation and drilling blasting.

22 CONSTRUCTION PROGRAM CYCLE TIME ACCORDING TO VARIOUS ROCKCLASS

MAIN TUNNEL							
Sr. No	Activity Description	Units	Class 1	Class 2	Class 3	Class 4	Class 5
1	Survey & Marking	Minutes	60	60	60	60	60
2	Drilling	Minutes	133	93	97	75	0
3	Loading	Minutes	45	45	40	35	0
4	Blast	Minutes	5	5	5	5	0
5	Defuming	Minutes	30	30	30	30	30
6	Mucking	Minutes	191	130	135	110	115
7	Scaling	Minutes	30	30	30	30	0
8	Excavation of Face by Twin Cutter	Minutes	0	0	0	0	240
9	R/bolts & Forepoles	Minutes	0	33	44	53	181
10	Lattice girder	Minutes	0	0	0	60	90
11	W/mesh	Minutes	0	0	30	45	60
12	S.crete	Minutes	102	101	107	123	128
13	Down Time of Equipment	Minutes	90	90	90	90	90
14	**Total Time**	**Minutes**	**686**	**618**	**668**	**717**	**994**
15	**Time to complete 01 cycle**	**Hrs**	**11.4**	**10.3**	**11.1**	**11.9**	**16.6**
	Pull achieved	**Mtr**	**3.0**	**2.0**	**2.0**	**1.5**	**1.5**
Progress Achieved considering 20 hrs/Day		**Mtr**	**5.3**	**3.9**	**3.6**	**2.5**	**1.8**

Tunnel T-9						
Length of Rock classification	**Mtr**	**0**	**0**	**530**	**800**	**140**
No. of Days required	**Days**	**0**	**0**	**148**	**319**	**77**
Progress per month (considering 28 days/month)	**Mtr**	**147**	**109**	**101**	**70**	**51**
Time taken	**Months**	**0.00**	**0.00**	**5.27**	**11.38**	**2.76**
Total Time Taken to complete the tunnel	**Months**	**19.41**				
Average Progress / month	**Mtr**	**76**				

Tunnel T-9A						
Length of Rock classification	Mtr	0	0	0	110	140
No. of Days required	Days	0	0	148	319	77
Progress per month (considering 28 days/month)	Mtr	147	109	101	70	51
Time taken	Months	0.00	0.00	0.00	1.56	2.76
Total Time Taken to complete the tunnel	Months	4.33				
Average Progress / month	Mtr	58				

Tunnel T-10						
Length of Rock classification	Mtr	0	0	0	260	140
No. of Days required	Days	0	0	148	319	77
Progress per month (considering 28 days/month)	Mtr	147	109	101	70	51
Time taken	Months	0.00	0.00	0.00	3.70	2.76
Total Time Taken to complete the tunnel	Months	6.46				
Average Progress / month	Mtr	62				

Tunnel T-11						
Length of Rock classification	Mtr	0	0	270	400	140
No. of Days required	Days	0	0	148	319	77
Progress per month (considering 28 days/month)	Mtr	147	109	101	70	51
Time taken	Months	0.00	0.00	2.68	5.69	2.76
Total Time Taken to complete the tunnel	Months	11.14				
Average Progress / month	Mtr	73				

Tunnel T-12						
Length of Rock classification	Mtr	0	0	340	800	140
No. of Days required	Days	0	0	148	319	77
Progress per month (considering 28 days/month)	Mtr	147	109	101	70	51
Time taken	Months	0.00	0.00	3.38	11.38	2.76
Total Time Taken to complete the tunnel	Months	17.52				
Average Progress / month	Mtr	73				

Tunnel T-12A						
Length of Rock classification	Mtr	0	0	0	0	140
No. of Days required	Days	0	0	148	319	77
Progress per month (considering 28 days/month)	Mtr	147	109	101	70	51
Time taken	Months	0.00	0.00	0.00	0.00	2.76
Total Time Taken to complete the tunnel	Months	2.76				
Average Progress / month	Mtr	51				

Tunnel T-13						
Length of Rock classification	Mtr	0	0	560	900	140
No. of Days required	Days	0	0	148	319	77
Progress per month (considering 28 days/month)	Mtr	147	109	101	70	51
Time taken	Months	0.00	0.00	5.57	12.80	2.76
Total Time Taken to complete the tunnel	Months	21.13				
Average Progress / month	Mtr	76				

Tunnel T-14						
Length of Rock classification	Mtr	0	0	1010	1000	140
No. of Days required	Days	0	0	148	319	77
Progress per month (considering 28 days/month)	Mtr	147	109	101	70	51
Time taken	Months	0.00	0.00	10.04	14.22	2.76
Total Time Taken to complete the tunnel	Months	27.03				
Average Progress / month	Mtr	80				

23 CALCULATION OF CYCLE TIME

23.1 ROUND LENGTH FOR SUPPORT CLASS I TO V

Description	Unit	Class 1	Class 2	Class 3	Class 4	Class 5
Area of face	Sq. m	51.04	52.11	54.17	54.17	56.56
Area including swelling factor (1.5 to 1.63%)	Sq. m	76.56	78.165	81.255	88.2971	92.1928
Drilling of 1 m hole by boomer	Seconds	40	40	40	40	0
Removing drill rod from hole	Seconds	5	5	5	5	0
Placing rod for other hole	Seconds	5	5	5	5	0
Drilling of one complete hole	Seconds	134.4	89.6	89.6	67.2	0
Drilling length for one hole to achieve the desired pull	M	3.4	2.2	2.2	1.7	1.7
Total Time for one hole	Seconds	144.4	99.6	99.6	77.2	0
Total Time for one hole	**Minutes**	**2.41**	**1.66**	**1.66**	**1.29**	**0.00**
Excavation of Face by Twin Cutter/Road header	**Minutes**					**240**
Pull achieved	**M**	**3**	**2**	**2**	**1.5**	**1.5**
No. of holes to be drilled in face	**No's.**	**110**	**113**	**117**	**117**	**0**
Total time taken for Face drilling	**Minutes**	**265**	**187**	**194**	**151**	**0**
Drilling time by 2 booms	**Minutes**	**133**	**93**	**97**	**75**	**0**
Loading of face	**Minutes**	**45**	**45**	**40**	**35**	**0**
Blast	**Minutes**	**5**	**5**	**5**	**5**	**0**
Defuming	**Minutes**	**30**	**30**	**30**	**30**	**30**
Total volume of muck for the desired pull incl. swelling factor	**Sq. m**	**229.68**	**156.33**	**162.51**	**132.45**	**138.29**

23.2 MUCKING TIME CALCULATIONS

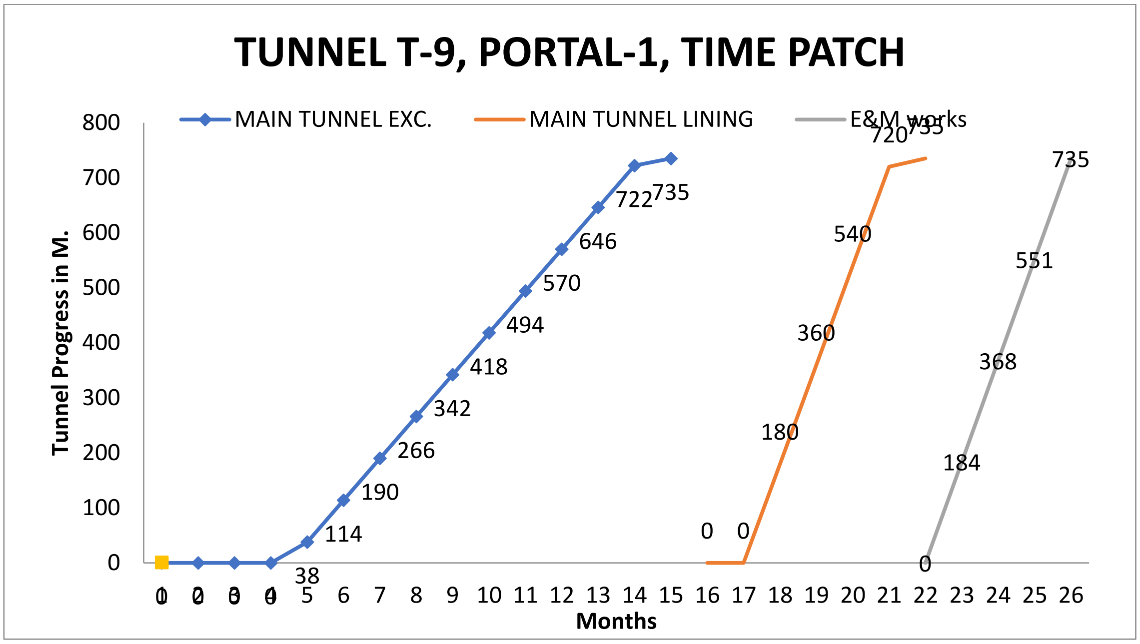
Activity Description	Units	Class 1	Class 2	Class 3	Class 4	Class 5
Assume Lead (Open + Tunnel)	Km	3	3	3	3	3
Excavator capacity	Cum/hr	45	45	45	45	45
Dumper capacity	cum/hr	10	10	10	10	10
Positioning of dumper	Min.	2	2	2	2	2
Loading of dumper	Min.	13	13	13	13	13
Travelling @ 15Km/hr	Min	8	8	8	8	8
Unloading of dumper	Min.	2	2	2	2	2
Return @20Km/hr	Min.	6	6	6	6	6
Misc. Time	Min.	2	2	2	2	2
Total Time	Min.	33	33	33	33	33
Qty. of muck hauled per unit per hour	Cum	18	18	18	18	18
Total vol. of muck	Cum	230	156	163	132	138
Assuming Dumpers	no's	4	4	4	4	4
Time taken to complete the muck	Hr	3.19	2.17	2.26	1.84	1.92

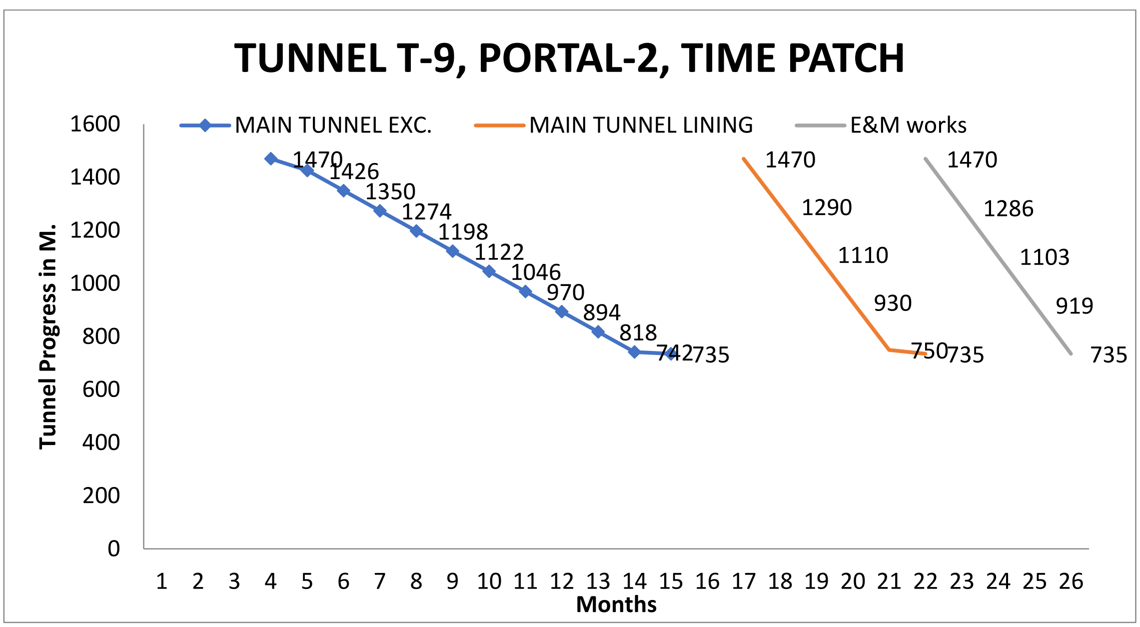
23.3 ROCK SUPPORT TIME CALCULATIONS

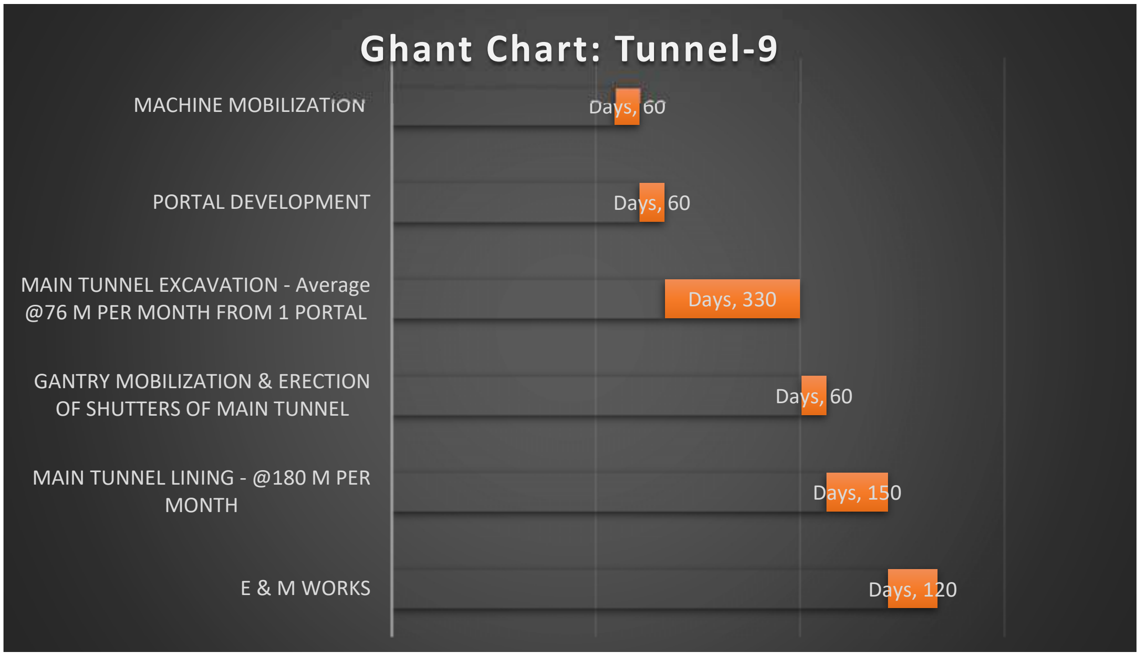
Description	Unit	Class 1	Class 2	Class 3	Class 4	Class 5	Column1
		R/Bolts	**R/Bolts**	**R/Bolts**	**R/Bolts**	**R/Bolts**	**Forepoles**
Drilling of 1 m hole by boomer	Seconds		40	40	40	40	40
Removing drill rod from hole	Seconds		5	5	5	5	5
Placing rod for other hole	Seconds		5	5	5	5	5
Drilling of 3 m hole	Seconds		120				
Drilling of 4 m hole	Seconds			160	160		160
Drilling of 6 m hole	Seconds					240	
Total Time for one hole	Seconds		130	170	170	250	170
Inserting R.bolts incl. Resin capsules	Seconds		120	120	120	150	120
Total Time for one hole	**Min.**		**4.17**	**4.83**	**4.83**	**6.67**	**4.83**
No. of R/bolts	**No's**		**8**	**9**	**11**	**9**	**25**
Total Time	**Min.**	**0**	**33**	**44**	**53**	**60**	**121**

Other Supports in MAIN TUNNEL							
Activity Description	Units	Class 1	Class 2	Class 3	Class 4	Class 5	Mechanical Excavation
Lattice Girder	Minutes	0	0	0	60	90	60
Wiremesh	Minutes	0	0	30	45	60	60
Shotcrete	Minutes						
Surface area for shotcrete	M^2	20.2	20.2	20.3	20.43	21.07	21.07
Thickness of shotcrete	mm	50	50	100	200	200	200
Qty. of shotcrete /mtr	Cum	1.0	1.0	2.0	4.1	4.2	4.2
Qty. of shotcrete for one round length	Cum	3.03	2.02	4.06	6.13	6.32	3.16
Shotcrete M/c set-up	Minutes	30	30	30	30	30	30
T.M arriving time from B/Plant (Parallel activity)	Minutes	0	0	0	0	0	0
T.M positioning	Minutes	5	5	5	10	10	5
Shotcrete Spraying assume 30m3/hr	Minutes	16.515	16.010	22.030	33.065	38.161	16.580
Shotcrete Machine removing	Minutes	20	20	20	20	20	20
Total Time taken	**Minutes**	**72**	**71**	**77**	**93**	**98**	**72**
Breakdown/ Maintenance	**Minutes**	**30**	**30**	**30**	**30**	**30**	**30**
Final Time taken	**Minutes**	**102**	**101**	**107**	**123**	**128**	**102**

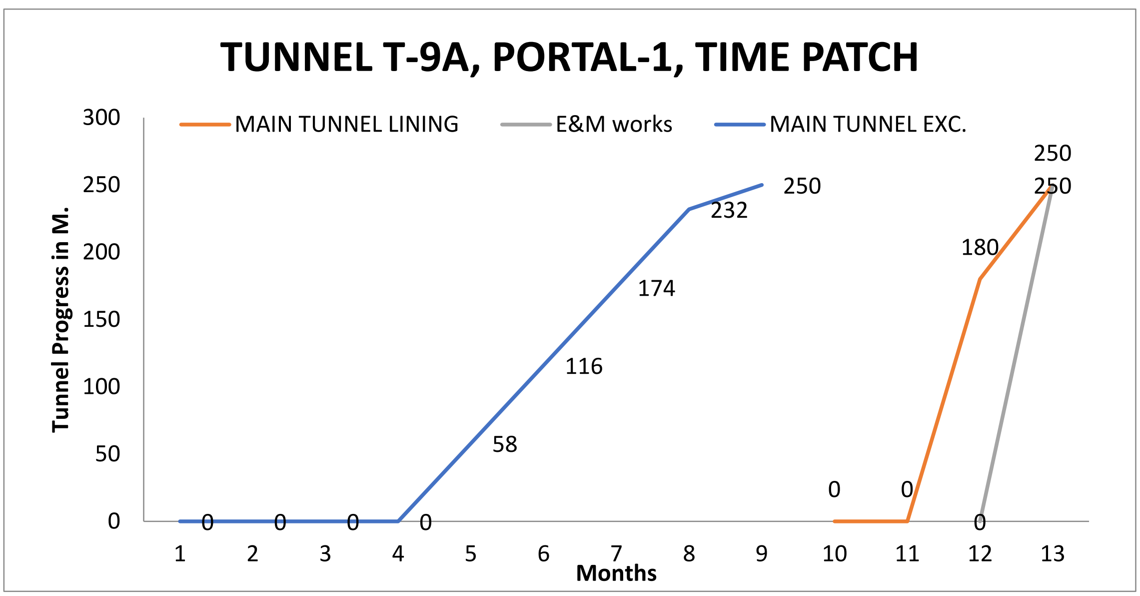
23.4 CONSTRUCTION PRORGRAM TUNNEL T-9 & T-14

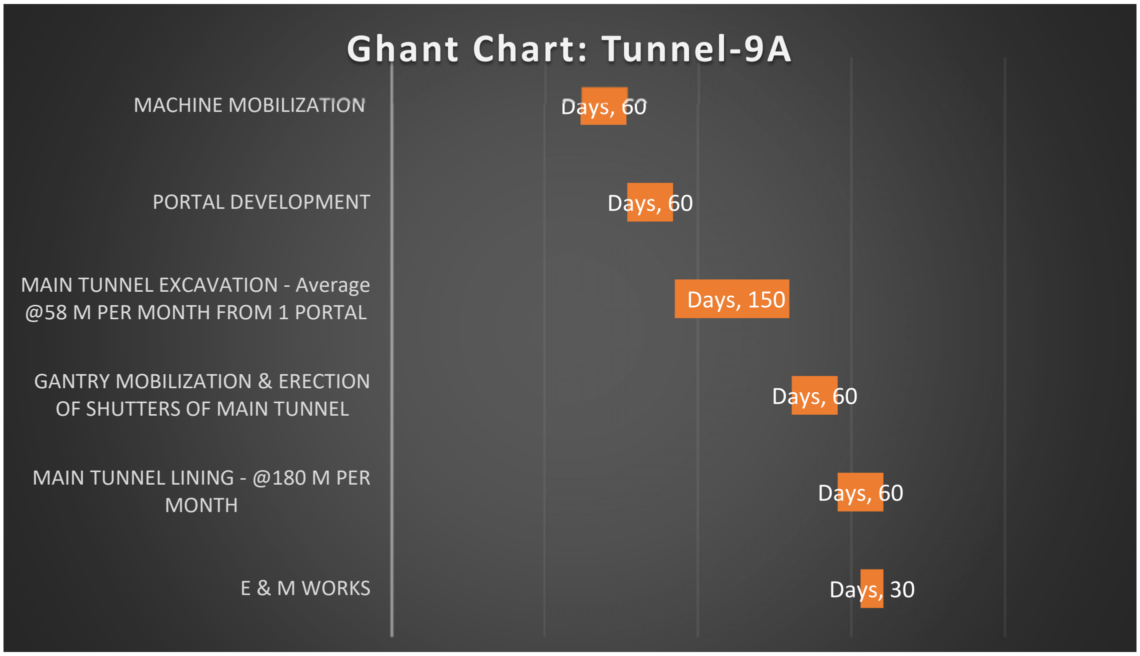




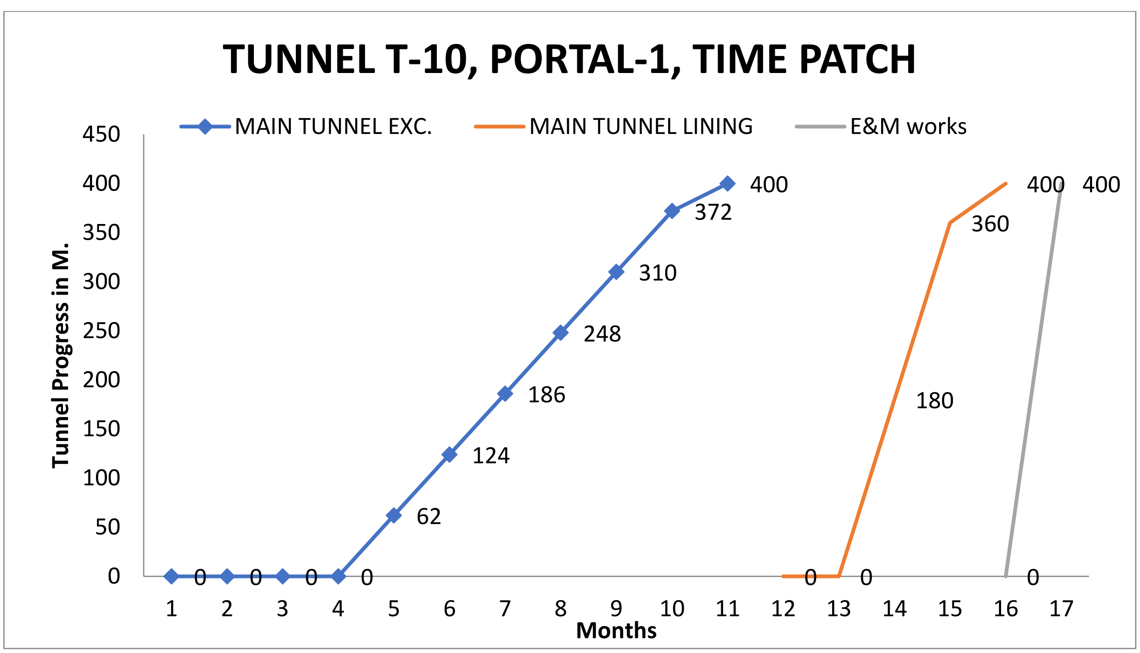


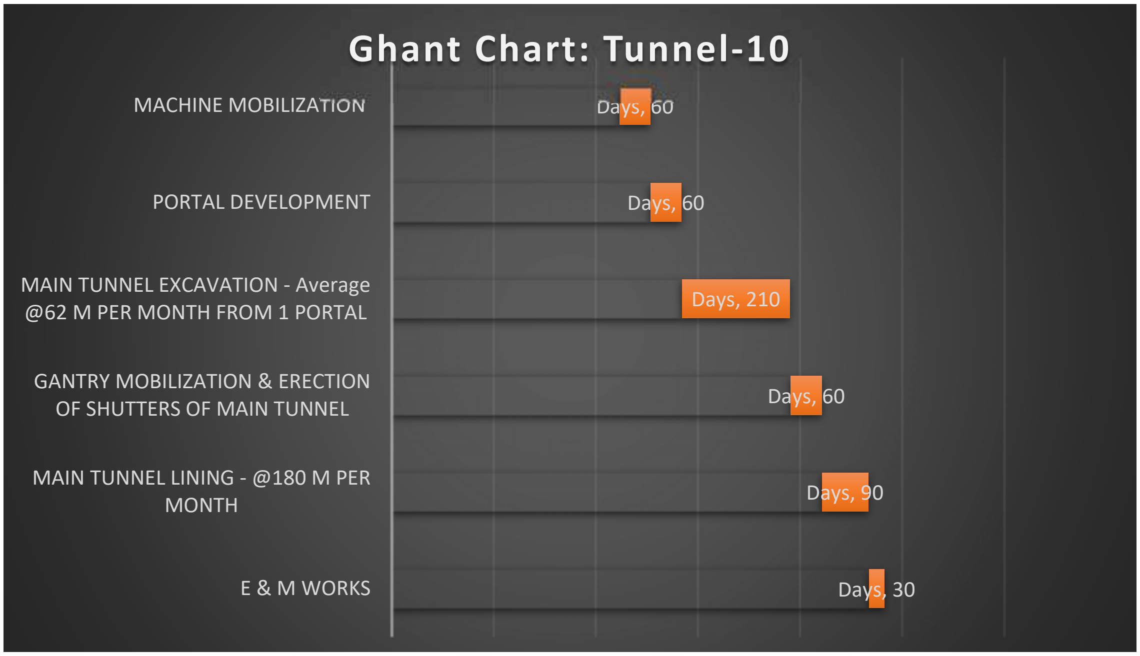
The Total time for construction of Tunnel-9 is calculated to be 26 months if the scheme recommended is followed judiciously.



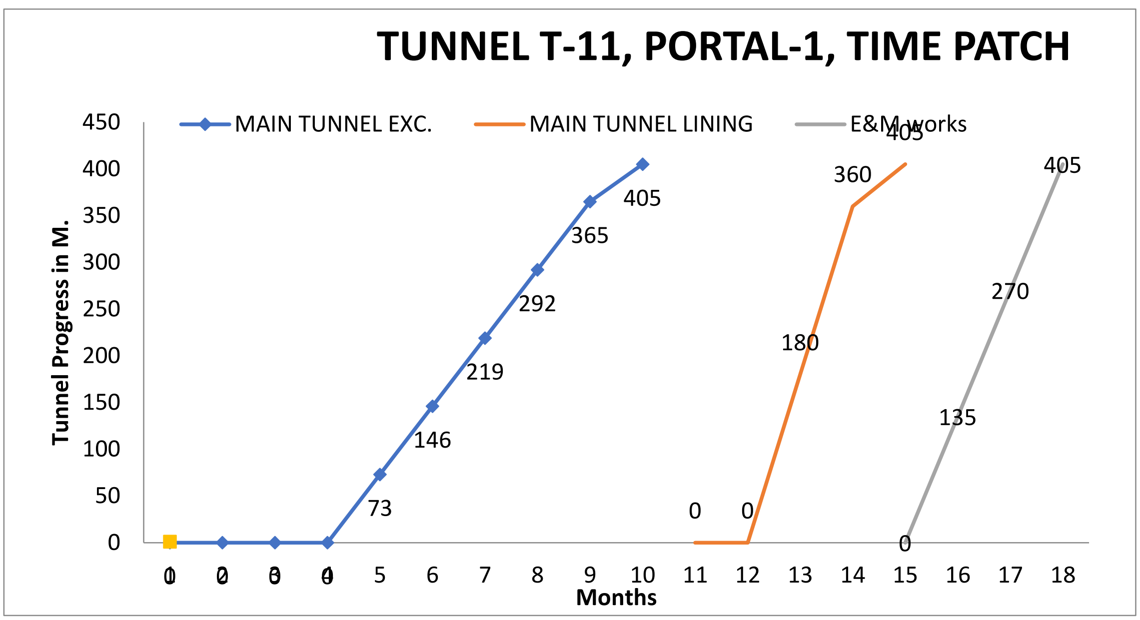


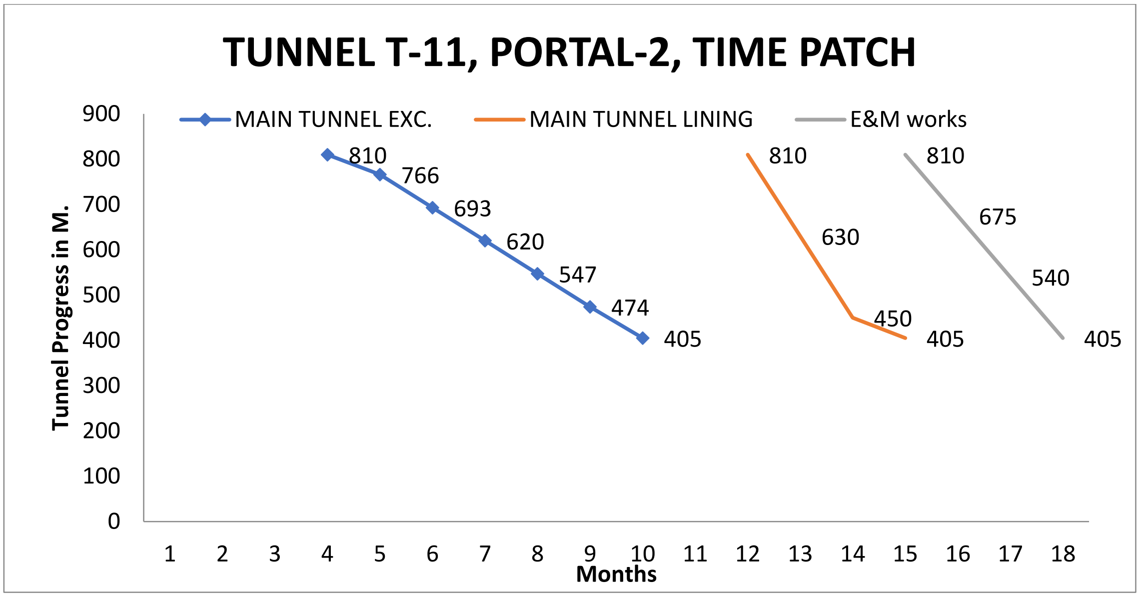
The Total time for construction of Tunnel-9A is calculated to be 13 months if the scheme recommended is followed judiciously.

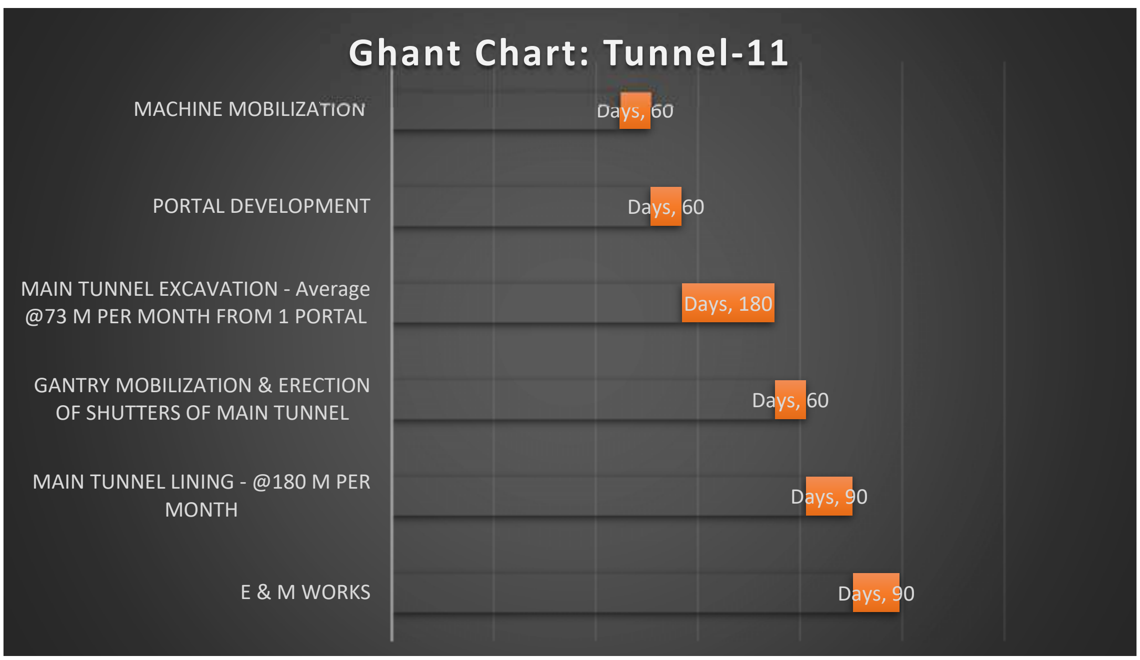




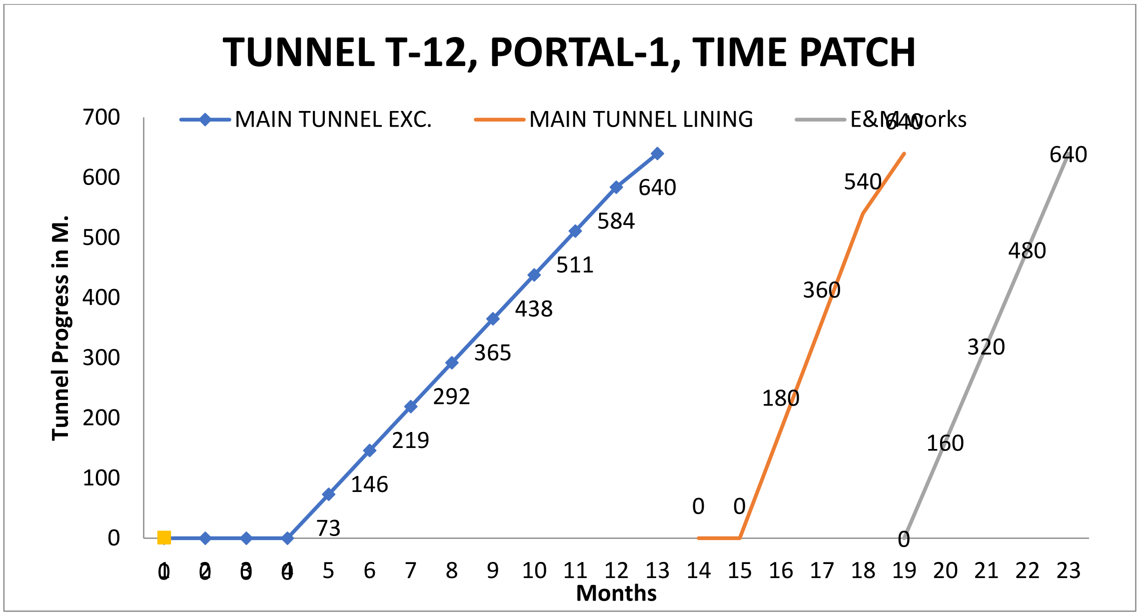
The Total time for construction of Tunnel-10 is calculated to be 17 months if the scheme recommended is followed judiciously.

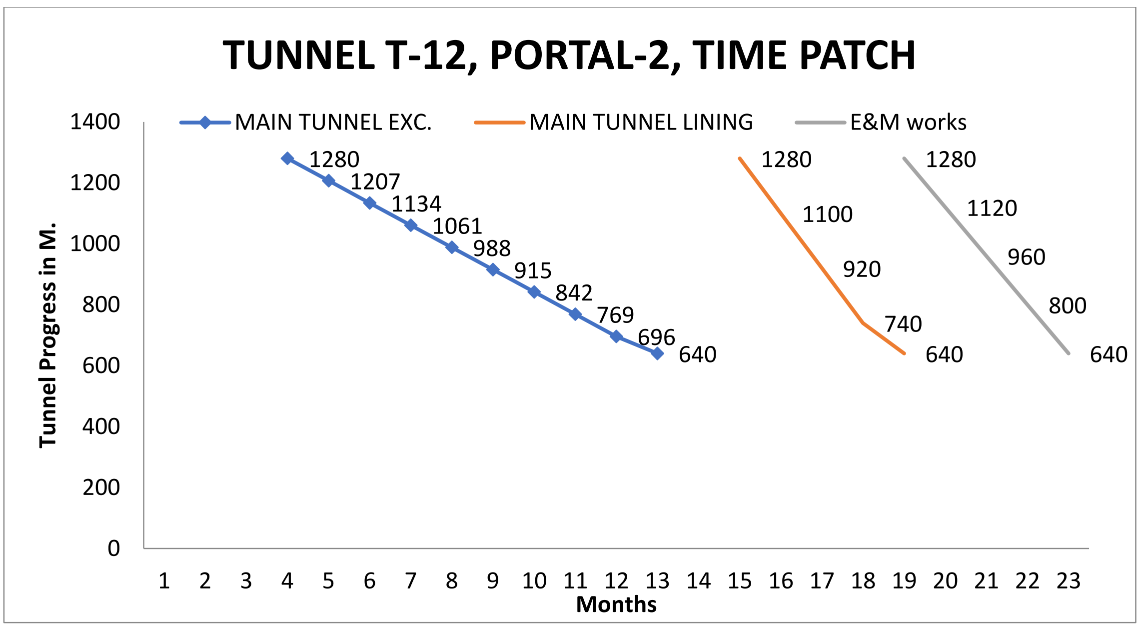


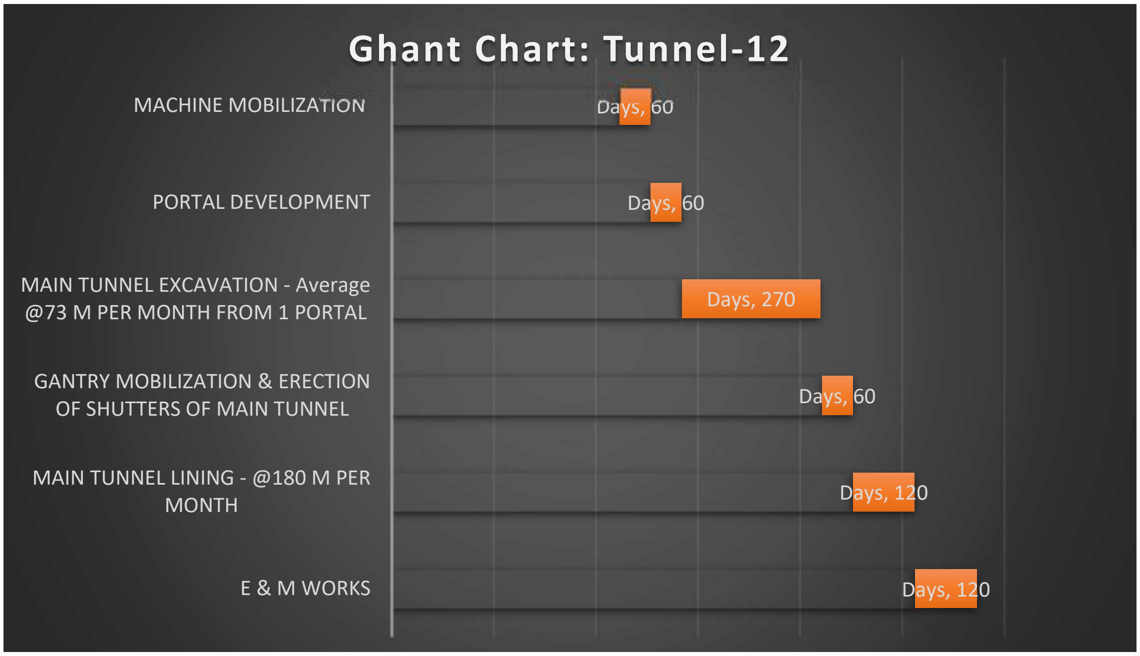




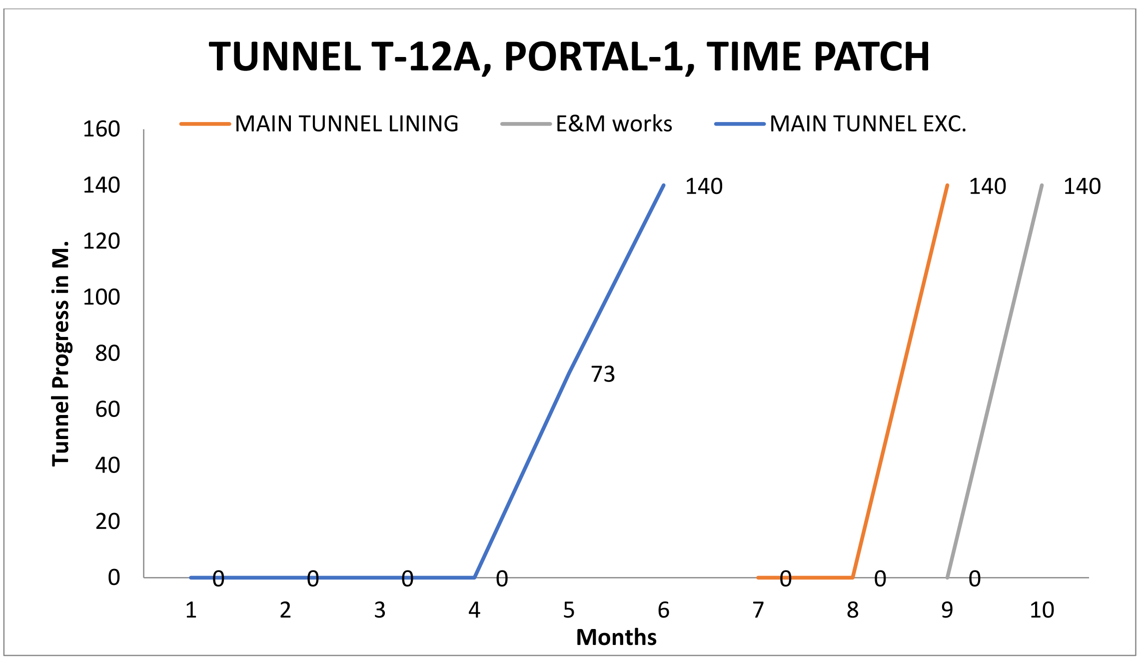
The Total time for construction of Tunnel-11 is calculated to be 18 months if the scheme recommended is followed judiciously.

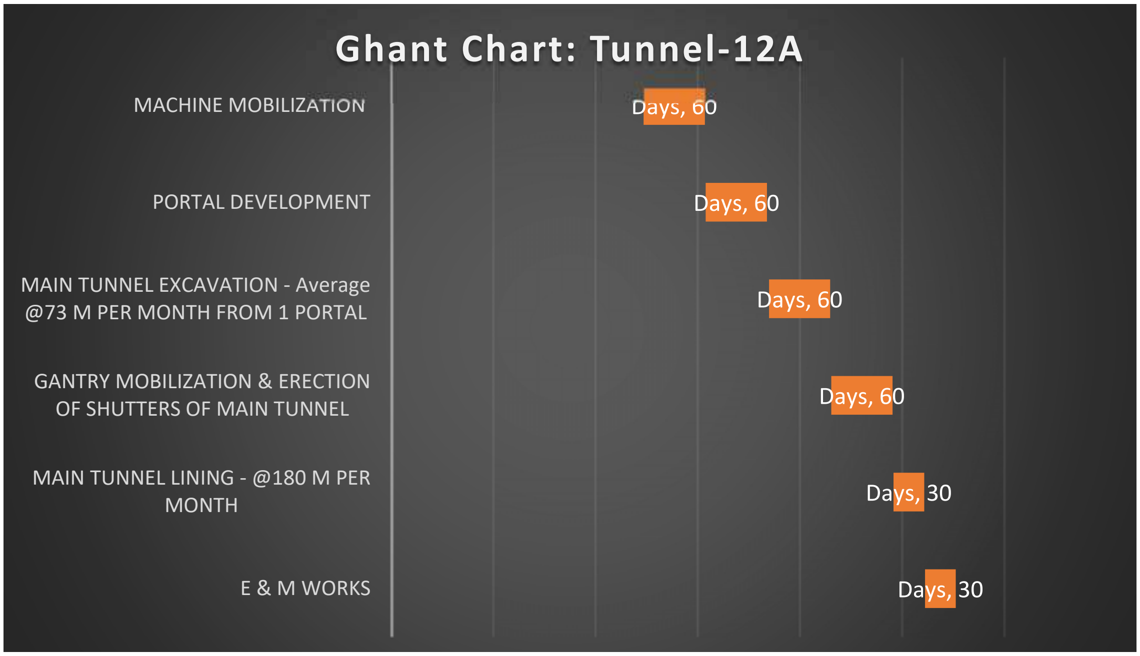

TUNNEL T-12, PORTAL-1, TIME PATCH
MAIN TUNNEL EXC.
MAIN TUNNEL LINING
E&M works
Tunnel Progress in M.
Months
0
73
146
219
292
365
438
511
584
640
0
0
180
360
540
640
0
160
320
480
640


TUNNEL T-12, PORTAL-2, TIME PATCH
MAIN TUNNEL EXC.
MAIN TUNNEL LINING
E&M works
Tunnel Progress in M.
Months
1280
1207
1134
1061
988
915
842
769
696
640
1280
1100
920
740
640
1280
1120
960
800
640

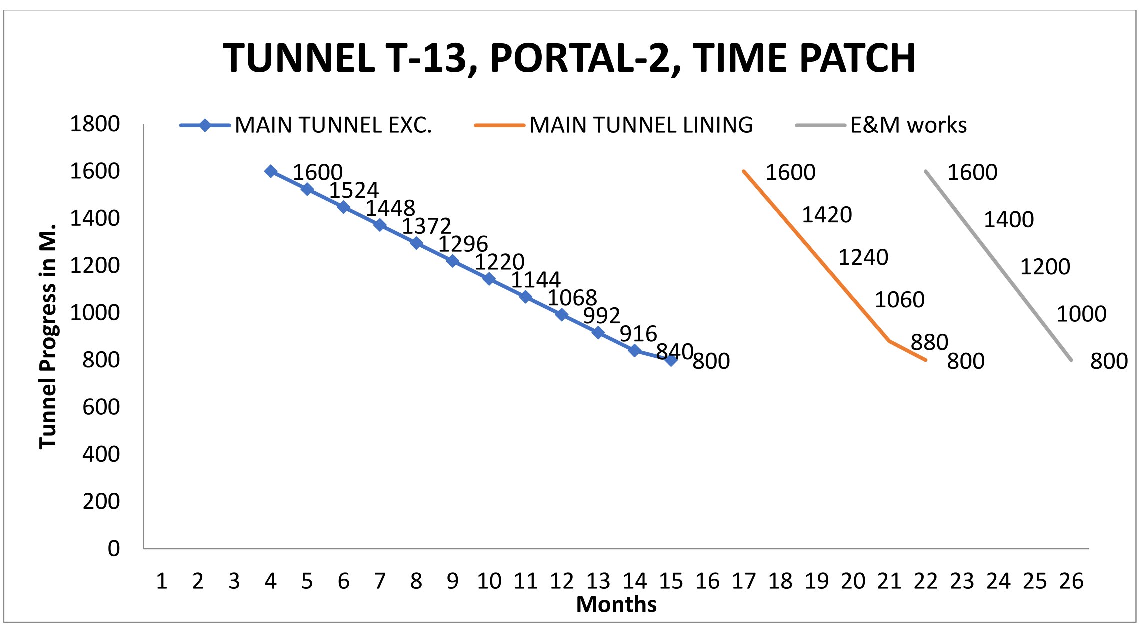


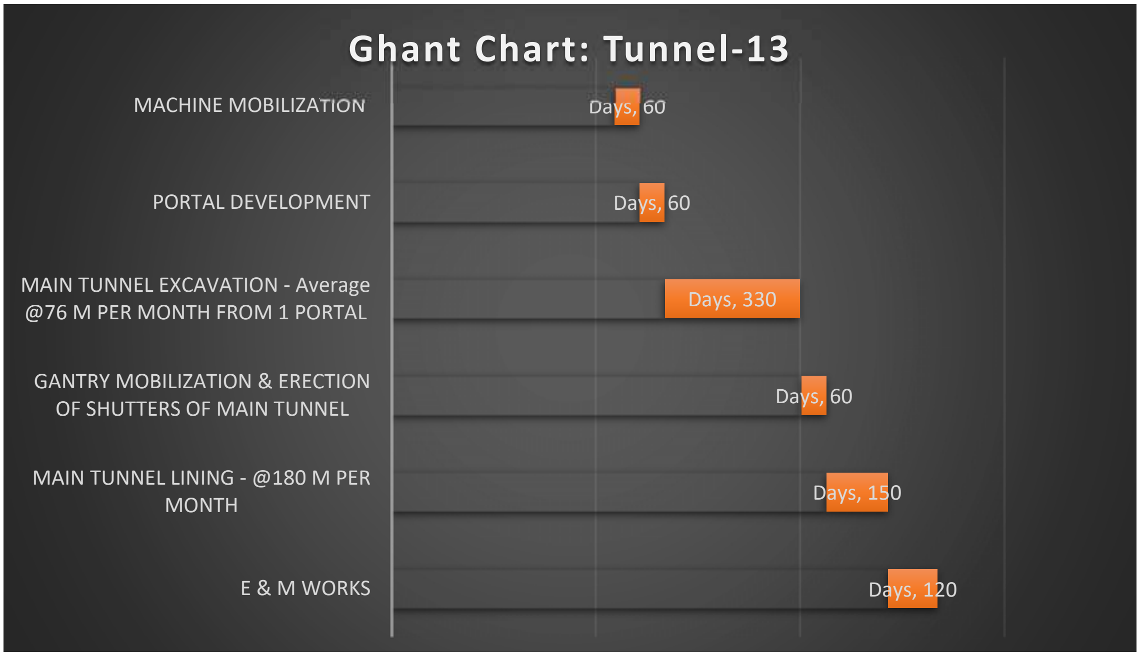
The Total time for construction of Tunnel-12 is calculated to be 23 months if the scheme recommended is followed judiciously.



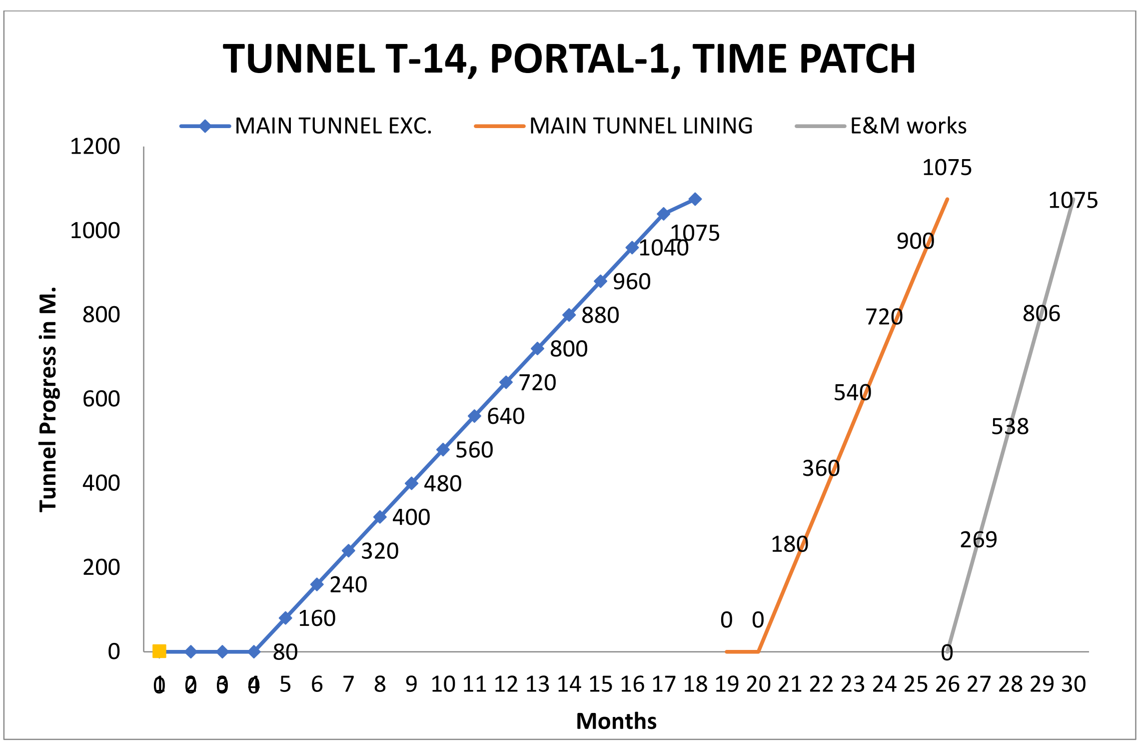


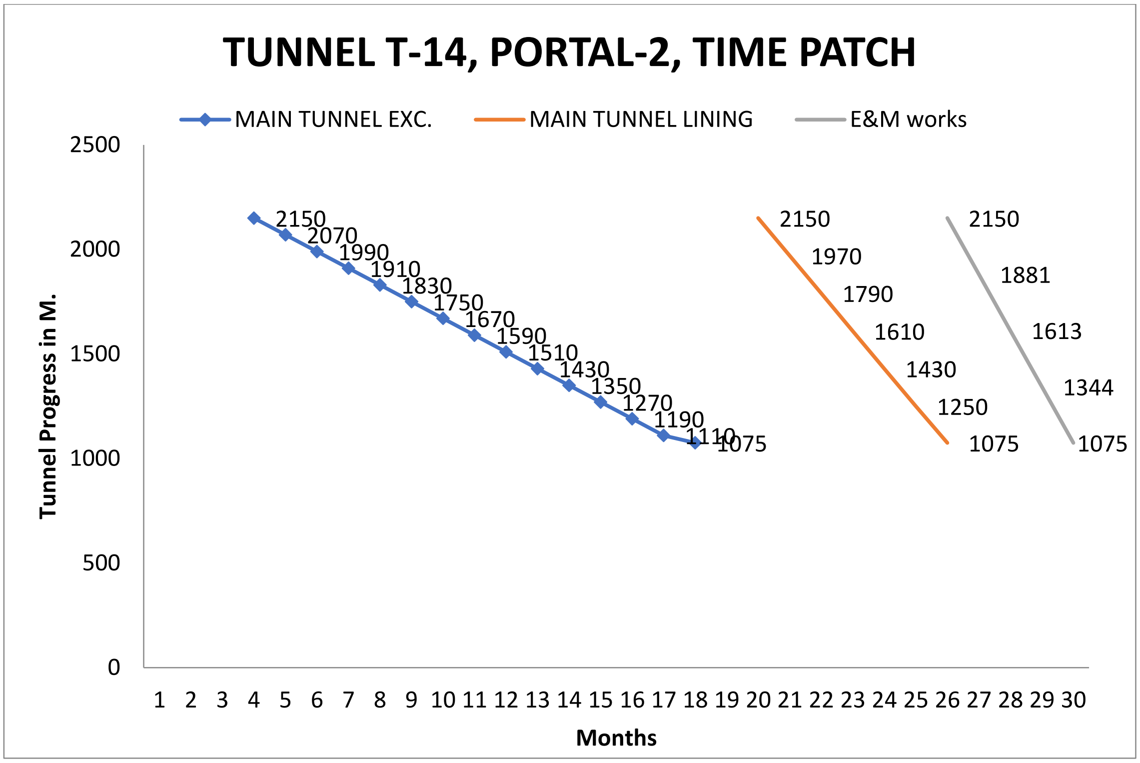
The Total time for construction of Tunnel-12A is calculated to be 10 months if the scheme recommended is followed judiciously.

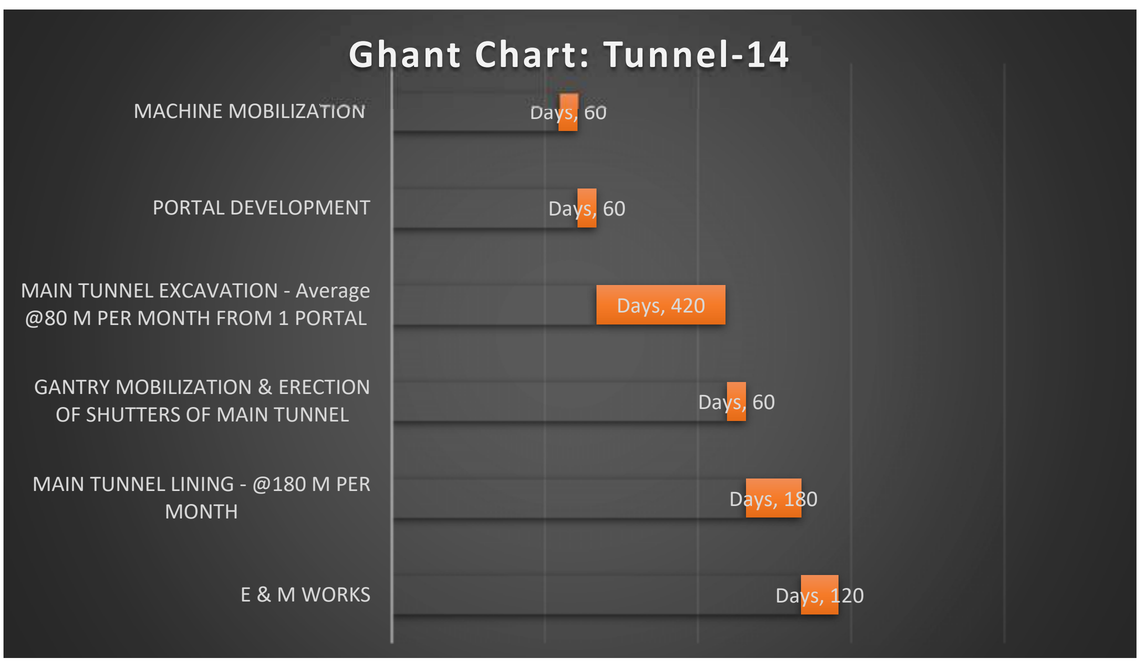




The Total time for construction of Tunnel-13 is calculated to be 26 months if the scheme recommended is followed judiciously.







The Total time for construction of Tunnel-13 is calculated to be 30 months if the scheme recommended is followed judiciously.

24 Objective of Ventilation in tunnels

The objective of the ventilation report is to access the tunnel for requirement of artificial ventilation. As the majority of tunnel length is less than 1000 m , no ventilation is required and only T-9,T-12,T-13 & T-14 are more than 1000m , therefore detailed ventilation system needs to be checked for the following four tunnels. **Detailed Calculation in Annexure -3 (NOT APPLICABLE)**

25 Item Rate Cost Estimate of Tunnels (Civil Works,BLT)

The item rate cost estimate is based on 9 LAR's of recently awarded tunnel contracts based on Item Rate Model. Refer Annexure-4 for details.